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Development of Adjustment Factors for On-Road Fuel Economy

Energy and Environmental Analysis, Inc.
Arlington, VA

Prepared for

Environmental Protection Agency
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The purpose of this analysis has been to evaluate and quantify the differences between EPA test-measured and actual on-road fuel economy. It is expected that the methodology and the adjustment factors developed in this analysis will form the basis for a labeling system that, in future model years, will discount the EPA test measurements of new cars to estimate on-road fuel economy. Because new cars employ a growing percentage of fuel efficient technologies having distinctly lower levels of shortfall than traditional ones, this analysis has carefully evaluated and, to the extent that available data permit, quantified the shortfall of the alternative technologies.

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The research described in this report was conducted by Energy and Environmental Analysis, Inc., Arlington, Virginia for the Enviornmental Protection Agency, Ann Arbor, Michigan 48105, under contract 68-03-2888 Task Order No. 8.

The work was performed by Mr. Robert Crawford, Mr. Peter Forshay, and Mr. Robert Dulla, the project manager. Engineering guidance was supplied by Mr. K.G. Duleep.

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1. INTRODUCTION

1.1 BACKGROUND

In response to growing consumer criticism of the difference, or shortfall, between EPA and on-road fuel economy, Congress mandated a detailed EPA investigation of the causes of shortfall in Section 404 of the National Energy Conservation Policy Act of 1978. EPA's "404 Report" quantified the difference between EPA and on-road mpg and developed the technical information necessary to formulate a fuel economy system capable of providing realistic mpg values. In February of 1980 hearings were conducted by a subcommittee of the United States House of Representatives to identify technical and policy problems with the current fuel economy information program. The subcommittee recommended that EPA devise a new mpg system for labeling new cars and for the Gas Mileage Guide.

In response to these Congressional recommendations, EPA has initiated rulemaking proceedings to "improve the usefulness of vehicle fuel economy labels and the accuracy and completeness of the data used for determining Corporate Average Fuel Economy (CAFE) levels for new passenger automobiles and light trucks." As part of that process EPA issued an Advanced Notice of Proposed Rulemaking that outlined 10 regulatory options to improve the value of the fuel economy program. Two of these options are designed to apply adjustment factors to label values, either single mode or dual mode, to account for the industry average difference between EPA measured and actual on-road fuel economy.

This report describes the work performed by Energy and Environmental Analysis, Inc., in the development and specification of fuel economy adjustment factors under Task Order No. 8 of EPA Contract No. 68-03-2888.

1.2 SCOPE OF THE ANALYSIS

The objective of this task is to develop adjustment factors that eliminate the average difference between EPA and on-road mpg which will be applied to 1983 and later model year new cars. In order for these factors to accurately account for the shortfall of future model year cars, they must account for changing vehicle designs. Therefore, EPA specified that the analysis investigate the sensitivity of shortfall to the following determinants of vehicle design:

- Four, six, and eight cylinder engines
- Automatic and manual transmissions
- Front and rear wheel drive vehicles
- Compression ignition (diesel) and spark ignition engines
- Combination of the above categories.

EPA required that the study produce specific adjustment factors for city, highway, and combined cycle values. In addition, the adjustment factors are required to be sensitive to the primary causes of shortfall. An analysis of the relation between in-use fuel economy, odometer reading, and related shortfall was specifically requested. Also requested was a comparison of in-use fuel economy reported by the general automotive press and EPA label values. To the extent possible, the comparison is supposed to discuss the causes of differences in the mpg values measured by the EPA and the automotive press.

The next section provides a review of the causes of shortfall and an outline of the analysis presented in this report.

2. OVERVIEW OF THE ANALYSIS

2.1 INTRODUCTION

Consumer and Congressional concern with the accuracy of EPA fuel economy figures prompted several organizations to undertake studies in the late 1970's of fuel economy shortfall, the difference between EPA and on-road fuel economy. Due to data limitations, these studies were restricted to quantifying levels of shortfall for selected model years. Unfortunately, they have provided very little insight into the fundamental causes of the difference between EPA and on-road mpg. However, they are in general agreement on two conclusions regarding observed trends in shortfall, for pre-1979 vehicles. First, the level of shortfall is related to the EPA fuel economy estimate; that is, shortfall increased with increasing EPA estimates. Second, shortfall on average appeared to increase with each model year. While it is not clear that these trends were mutually exclusive due to the increasing fuel economy of each model year fleet, it appears that the absolute level of shortfall has increased for each model year.

The purpose of this analysis is to quantify the current shortfall, and in so doing, to develop adjustment factors to eliminate the difference between EPA and average on-road mpg, which will be applied to future model year fleets. In order for these factors to be accurate and acceptable to both manufacturers and consumers, they must account for more than the aggregate performance of the existing fleet: the development of these factors also must account for the fundamental causes of shortfall and their implications for the on-road performance of future automotive technologies.

2.2 REVIEW OF EPA'S 404 REPORT

To date only one published study has evaluated the causes of shortfall. That study, known as the 404 report,[1/] was produced in response to a Congressional mandate to identify the causes of shortfall. One purpose of the report was to provide a technical basis for the formulation of a permanent system capable of providing accurate EPA estimates of mpg for labeling and publication in the DOE Gas Mileage Guide. Before developing the framework for the analysis in this report, it is instructive to review the 404 report's conclusions on the causes of shortfall.

The 404 report identified three primary causes of shortfall or "slip:" vehicle slip, road slip, and changes in vehicle design features.

Vehicle slip is defined to include the differences between the prototype vehicle tested by EPA for certification and the average production vehicle operated on the dynamometer, using the same test procedures. There are two components of vehicle slip: 1) production slip, or the difference between the vehicle configuration selected for testing and the predominant configuration operating on the road and 2) vehicle condition, which is primarily the difference between the state of tune of certification vehicles and actual in-use vehicles. The report quantifies the contribution of each of the above components to the fleet mpg shortfall. It also notes that mpg appears to increase over the first 50,000 miles of driving and that the phenomenon of increased shortfall for increasing EPA mpg does not occur until after the break-in period or the first 4,000 miles of driving. The influence of vehicle condition (e.g., vehicle alignment, brake drag, engine tune, and maintenance practices) on mpg appear to accumulate with increasing odometer readings. Thus, the cause of higher shortfall for higher levels of mpg may be related to vehicle condition.

Road slip is defined to include all differences between in-use operating conditions and conditions mandated for use on the EPA test. The 404 report separates in-use fuel economy sensitivity to these conditions into four categories:

- Travel Environment -- conditions under which travel occurs, such as temperature, wind, grade, and road surface.
- Travel Characteristics -- details of travel such as average speed, stopping frequency, trip length, and driving technique.
- Vehicle Condition Road -- matters of driver choice including mechanical condition, tire pressure, and load.
- Simulation Variance -- variances in the test procedure that could bias results such as tire/dynamometer interaction, performance of manual and automatic transmissions, and vehicle cooling.

The combined effects of wind, temperature, grade, and road surface can have a significant influence on in-use fuel economy performance. The 404 report notes that "the travel environment simulated by the EPA test is one that gives the best fuel economy of all possible environments." Thus, any deviation from the travel environment conditions simulated by the EPA test (e.g., operation at 30°F instead of the 68-72°F specified in the test) can lead to substantial levels of shortfall.

Travel characteristics such as speed, trip length, average miles per day, and acceleration directly influence the level of fuel economy performance. Their individual influences on mpg can be evaluated separately under laboratory testing conditions; however, due to their interrelated nature, their separate contributions to fuel economy and shortfall under in-use conditions cannot be evaluated. For example, long trips generally have high speeds, smooth accelerations, and relatively constant speeds. Short trips are characterized by relatively low speeds, a high frequency of starts and stops, and sharp acceleration changes. The 404 report noted that shortfall can be extremely sensitive to shifts in travel characteristics from those specified in the EPA test procedure, particularly speed and acceleration. Nevertheless, the report concludes that while travel characteristics are, on average, different from those specified in the EPA test, the shortfall is much less than might be expected due to the opposing effects of the differences in travel characteristics. It is important to note, however, that the 404 analysis developed shortfall estimates by comparing in-use mpg to the EPA composite value. An analysis of the sensitivity of shortfall due to the same shifts in travel characteristics for separate city and highway mpg estimates might produce significantly different results.

Shortcomings in the test procedures related to simulation variances were identified in the 404 report. Two test procedure changes designed to reduce any bias towards shortfall were discussed.

First, beginning with the 1979 model year, manual transmission shift point specifications were tightened to eliminate the use of "schedules tailored for good fuel economy and low emissions but unrepresentative of what could be expected in consumer driving."1/ This was designed to eliminate a bias in the EPA versus on-road fuel economy performance of manual relative to automatic transmissions.

The second test procedure change was a modification of the weight classification system beginning with the 1980 model year to reduce the potential for weight class maldistribution and the related fuel economy effects of dynamometer underloadings and overloadings. This was achieved through the addition of incremental test weight classifications.

In addition to vehicle slip and road slip, the 404 report also discusses the potential contributions of alternative vehicle design features to fuel economy shortfall. The design features that were studied included vehicle weight, engine displacement, N/V ratio, and transmission type.

No discernable trends in shortfall were identified for these design features other than the discrepancy between the relative performance of automatic and manual transmissions which was noted above. The report does, however, note that there is evidence that recently introduced fuel-efficient technologies "may reduce vehicle sensitivity to some real world conditions." Two technologies were cited for reduced shortfall, diesel engines and front wheel drive transmissions. A DOE report[2/] notes that diesel powered cars have almost one-half of the shortfall of comparable gasoline-powered cars. The 404 report indicated a two to five percent road mpg advantage for front wheel drive vehicles. The report does not analyze the engineering reasons for differential performance of these technologies under in-use conditions, nor does it pursue an analysis of the in-use mpg data. Nevertheless, the data indicate that these technologies are not nearly as sensitive to real world conditions or road slip as are traditional gasoline-fueled rear wheel drive cars.

2.3 SPECIFICATION OF SHORTFALL FACTORS TO BE CONSIDERED IN THE ANALYSIS

At this point it is valuable to consider the insights provided by the 404 report regarding the causes of shortfall and to determine the individual influences that should be accounted for in the development of adjustment factors. It is equally instructive to review the available data sources and determine what data are available to quantify the impact of these influences on observed shortfall.

The development of adjustment factors for 1982 and later model year cars will be based on data detailing the in-use performance of 1977-1980 model year cars. Analyses by the Department of Energy have indicated an increase in shortfall for each model year from 1976 through 1979. Part of this change is due to the increasing mpg of each new car fleet and the related increase in shortfall of higher mpg cars due to the apparent increased sensitivity of higher mpg cars to road slip. However, part of the change in shortfall also is due to a variety of influences that change from one year to the next. This analysis must therefore identify those influences that either have changed or will change with time, evaluate their relative contribution to shortfall, and develop adjustment factors that are sensitive to them.

The influences listed in the 404 report that appear to change with time and should be included in this analysis are listed below:

- Technology
- Odometer mileage
- City/highway distribution
- Test procedure changes.

The current and anticipated sustained demand for increased fuel economy will radically alter the mix of technologies available in future new car fleets. There are numerous engineering reasons that suggest that the mpg performance of these relatively new or alternative technologies are not as sensitive to in-use conditions as are traditional gasoline-fueled, carburetted, rear wheel drive cars. For example, because diesels require very little cold start enrichment, they are not as sensitive to cold weather operation as carburetted cars. Fuel injected gasoline cars also require less enrichment during cold start as well as decreased acceleration enrichment in comparison to carburetted cars and, therefore, should suffer less shortfall. To the extent that there are data available which detail the performance of alternative technologies for 1978-1980 model cars, they should be analyzed to determine differential levels of shortfall.

The 404 report indicates that mpg appears to rise over the first 50,000 miles of use and that there is a definite relationship between vehicle slip and odometer mileage. It also notes that the odometer reading can be considered as a surrogate for the state of maintenance of the car, a factor that changes with the age of the vehicle and clearly influences shortfall. Because the available data sources cover a wide range of odometer readings, it is important to determine whether the influence of odometer mileage on shortfall is large enough to warrant conversion of the data base to a consistent odometer mileage.

It is clear from the 404 report and related publications that in-use fuel economy is extremely sensitive to both travel characteristics and the travel environment. The 404 report, however, indicates that the countervailing differences between measured in-use conditions and those specified in the test procedure (shifts in travel characteristics) result in a relatively small net shortfall for the EPA composite figures. This assumes that the split of in-use driving is roughly proportional to the 55/45 weighting of EPA's city and highway measurements. Recent analysis of the J.D. Power data[3/] indicates that travel behavior is bi-polar; that is, a relatively large percentage of drivers use their cars primarily in the city and a large percentage of drivers use their cars primarily on the highway. Few drivers exhibit a 50/50 split between city and highway travel. Thus, on average, a driver's travel behavior represents the weighting of the EPA composite figure but the potential for shortfall in the consumer's individual driving environments is much greater than the comparison of average in-use mpg to the composite EPA figure indicates. Therefore, it is necessary for this analysis to evaluate the shortfall associated with city and highway driving cycles. In the past, data on the percent distribution of city and highway driving and related in-use fuel economy performance have been extremely limited. Two data bases, J. D. Power and Ford, recently have become available to make the analysis of this shortfall behavior possible.

One additional influence that definitely has changed with time has been the changes in protocol for the EPA test procedure. While it is not necessary for the adjustment factors to specifically account for the influences of these changes, it is important to remember their influence when interpreting changes in shortfall for individual model years and technology categories.

2.4 EPA GUIDANCE ON THE FORM OF THE ADJUSTMENT FACTORS

The previous discussion of the real world influences that cause differences between EPA and on-road mpg makes it clear that there are many possible mathematical specifications that can be used in the development of adjustment factors. The adjustment factors also will be influenced by the labeling strategy employed. Current labels provide only a single mpg value -- the city value. However, manufacturer advertising continues to give emphasis to the highway value. EPA addressed the question of what type of information the labels are intended to display in a recent rulemaking support document.[4/] In that report six labeling strategies were prepared.

Four strategies addressed variations of a two-mode (city and highway) approach and two strategies discussed a one-mode (a combined city and a composite) approach. The relative advantages and disadvantages of each strategy were extensively discussed. The report concluded that:

> "Either of the one-number systems would be somewhat 'cleaner' than multi-number systems in the cosmetic sense, offering less clutter in the label and Guide; however, reducing clutter may not provide all the information desired by consumers."

The report also noted that a large percentage of consumers at recent focus group sessions favored a multi-number system. The desire to receive the multi-number information system reinforces the technical reasons presented in the previous section for a separate analysis of city and highway shortfall.

EPA guidance on the form of the adjustment factors indicated that the final method must account for trends observed in the data, yet be capable of implementation in the rulemaking.

2.5 OUTLINE OF THE ANALYSIS

The organization of the remainder of the report follows from the previous discussion of shortfall influences. The study is organized as follows:

- Review of Existing Databases
- Odometer Analysis
- Combined Mode Analysis
- Two-Mode Analysis
- Survey of MPG Represented in Vehicle Publications
- Recommendations.

Section 3 provides a summary of data available for use in the analysis. A brief discussion of the individual data sources, their collection techniques, and limitations is presented. In addition, the methods used to eliminate outliers and biased data are described. Also presented are summaries of the model year, manufacturer, size class, and technology categories represented in the data.

The odometer analysis in Section 4 examines the dependence of on-road fuel economy on accumulated mileage. A methodology is presented for determining the magnitude of the effect of the odometer reading on shortfall. Analyses of two databases containing detailed odometer and in-use mpg data are presented.

Section 5 presents an evaluation of shortfall for composite EPA fuel economy values. A brief discussion of relevant analytical spaces (e.g., mpg, gpm, etc.) and means of measuring shortfall is presented. Technology categories are selected for examination based on expected response to shortfall influences. Regression analysis is used to evaluate the form and level of shortfall for each of the technology categories.

An assessment of the shortfall for two modes, city and highway, is presented in Section 6. The methodology and available databases relevant to the analysis are discussed. Linear and quadratic regression models are used to develop adjustment factors. Each of the models is reviewed for its ability to quantify shortfall performance.

At the request of EPA, a survey of the fuel economy information reported in automotive trade literature is presented in Section 7. The test procedures employed by individual magazines are reviewed and limitations are noted. A brief analysis of the differences between the mpg values reported in five publications and comparable EPA values for 1978-1980 model year vehicles is presented.

Section 8 summarizes the findings of this study and details EEA's recommendations for adjustment factors to be used in the upcoming rulemaking. Appropriate caveats are noted where data limitations prevent adequate analysis.

FOOTNOTES FOR SECTION 2

1/ U.S. Environmental Protection Agency. 1980. Passenger Car Fuel Economy: EPA and Road. EPA 460/3-80-010. Washington, D.C.: EPA, January.

2/ McNutt, Barry, et al. 1978. "Comparison of EPA and Lower Fuel Economy of 1974-1978 Automobiles." SAE Paper 780037. February.

3/ Energy and Environmental Analysis, Inc. 1981. Vehicle Purchase and Use Data Matrices: Volume I -- J.D. Power/DOE New Vehicle Owner Surveys. Arlington, VA: EEA, March 13.

4/ U.S. Environmental Protection Agency. 1980. Technical Support Report for Regulatory Action, Light Duty Vehicle Fuel Economy Labeling. Ann Arbor, MI: EPA, CTAB, October.

3. REVIEW AND CRITIQUE OF EXISTING DATA

3.1 DATA SOURCES

The creation of a data base of sufficient size to ensure adequate manufacturer and technology representation has been a continuing problem in this analysis. Due to resource limitations, the development of a data base through a testing program has not been possible. The lack of published in-use fuel economy data forced the collection of data from a variety of sources. There are three primary sources of data used in this analysis: DOE, Ford, and J. D. Power. A brief review of each is presented below.

3.1.1. DOE In-Use Fuel Economy Data Base[1/]

The DOE data base forms the core of the data used in the analysis. It contains information collected from a variety of fleet operations, testing organizations, State DOT's, oil companies, and automobile manufacturers for 1975-1980 model year cars. DOE has been collecting and compiling these data for the past three years. Also included in the data base is information on model year 1977 and 1978 cars collected under contract to DOE by Runzheimer, Inc., a commercial fleet management company.

The representativeness of the DOE data base was thoroughly analyzed in the 404 report. It concluded that the sample has three representational shortcomings:

- Imported cars are, for all practical purposes, not included in the sample
- The majority of the data base consists of information on rental or fleet cars

- Odometer readings are progressively higher for earlier model year cars. Thus, depending on the effect of accumulated mileage on fuel economy, the data could be biased.

3.1.2. Ford 1978, 1979, and 1980 Test Car Survey

These data were collected in a postcard survey of new Ford Motor Company vehicles leased to management-level employees on a yearly basis. The leased cars are used in personal as opposed to fleet service and are typically driven under a variety of conditions in most areas of the country. Fuel economy surveys were conducted in the winter and summer of 1978, 1979, and 1980. A valuable parameter collected in the survey was the estimate of urban driving fraction for each car. Due to time constraints, and the need for late model fuel economy, only the 1979 and 1980 Ford data were included in the analysis. The 1978 Ford data are represented by average model values in the DOE data base.

3.1.3. J. D. Power Survey

Under contract to DOE, J. D. Power, Inc. conducted a questionnaire survey to establish a data base for evaluating the EPA/DOE Fuel Economy Information Program's Gas Mileage Guide and fuel economy label. The survey was a nationwide random sample of approximately 10,000 buyers of new 1978 and 1979 vehicles from most domestic and import manufacturers. The purpose of the survey was to collect information that characterized decision-making criteria in the new vehicle purchase process. The survey also asked respondents to report their in-use fuel economy, their gas mileage record-keeping practices, and the accuracy and usefulness of the information presented in the Guide and label. As in the Ford survey, information on the percentage of urban driving was collected. There are two disadvantages to the in-use mpg data collected in this survey:

1. The in-use mpg values represent owner estimates of fuel economy and are not necessarily measurements (measured miles divided by measured gallons) of fuel economy. The accuracy of these estimates can be reviewed through a check on the record keeping behavior of the respondents. The survey question and potential responses are listed below.

DEFINITION OF FUEL ECONOMY RECORD-KEEPING CATEGORIES

(Source: Question 27 from J.D. Power Survey)

Code	Respondent's Record-Keeping Practice	Interpretation
1	Keeps accurate records at all times	Based on Records
2	Makes frequent checks of gas mileage	Based on Checks
3	Makes occasional checks on gas mileage	
4	Knows fairly well by what gasoline has been put in, but does not keep formal records	Based on Perception
5	Does not make any checks	
No answer given		

2. In order to determine the correct EPA value for each respondent's car, it is necessary to have the following information: make/model, engine size (CID), and transmission type/number of gears. The survey asked for information on the number of cylinders instead of the engine size; all of the other data required for determination of the correct EPA value were collected. Consequently, the EPA mpg values assigned to many of the vehicles represent the values of the sales leaders for each of the cylinder categories. Thus, depending on the mix of vehicles actually contained in the survey, the potential for a bias exists.

Table 3-1 summarizes the data used for the analysis and presents information on the source, model year, measurement type, and number of observations.

3.2 SELECTION OF DATA FOR USE IN THE ANALYSIS

The data base assembled for this study represents the largest collection of in-use fuel economy data available for analysis to date. As noted in Table 3-1, over 50,000 data points have been collected. Unfortunately, not all of these data can be used in the analysis due to inconsistencies in measurement techniques and biases in the data collection efforts discussed in the previous section. The purpose of this section is to review the criteria used to eliminate those inconsistencies in the data which might bias the analysis. The criteria selected to "cleanse" the data are listed below:

- Elimination of outliers
- Accumulated mileage
- Data source/driver cycle
- Record-keeping behavior
- Vehicle design characteristics.

Table 3-2 presents a list of the data rejected from the analysis based on these criteria. A brief discussion of the inconsistencies that the criteria are designed to eliminate is presented below.

Outliers are data points that appear to deviate substantially from other members of the same sample set. They can arise from errors in data collection or tabulation or they can represent accurate but rare occurrences. A wide variety of techniques exist for the identification, rejection, and accommodation of outliers.2/

Instead of employing a complex method of eliminating outliers, a simple approach was used to purge the data of obvious errors and rare observations. In-use values of fuel economy were rejected if they were less than 50 percent or more than 150 percent of the related EPA composite values. As shown in Table 3-2, this resulted in the elimination of approximately four percent of the data.

TABLE 3-1

DATA SOURCES

Source	Model Year	Data Type[1]	Total # of Data Points	Total # of Models
EPA Certification	75,76,77,78,79,80	4	5,405	1,804
Union Oil	75	4	413	68
DuPont	75,76,78	3,4	290	56
General Motors	75,76,78	3,	140	140
Mobil Oil	75,76,77,78	3,4	114	82
Shell Oil	75,76,77,79,80	3,4	161	68
Motor Trend	75,76,77	4	61	60
Shell Canada	75	3,4	42	12
Consumer Letters	75,76,77	3	140	72
Consumers Union	75,76,77	4	187	63
TRW	75,76,77	1	10	10
Maryland DOT	75,76,77,78	1	1,659	35
Maine DOT	75,76,77	1	9	9
EPA Emission Factors Data	75,76,77,78	2,4	5,957	436
Industrial Hydrocarbons	76	1	1	1
J. Glass Leasing	77	1	10	5
New Jersey DOE	75	1	153	3
Texaco Oil	75,76,77	3,4	75	41
EPA Portland I/M	75,76,77	2,4	4,651	188
API	75	1	2,133	35
AT&T	76,78,79	1	300	20
Amoco Oil	75,76,77,78,80	3	161	97
Wisconsin DOT	75,76,77,78,79,80	1,3	810	31
Illinois DOT	75,76,77,78	1,3	342	11
Runzheimer	77,78,79	1	6,132	99
SAE	75,76	4	169	33
Tennessee DOT	75,76,77,78	1,3	218	14
Libby Owens Ford	78	3	56	11
ARCO	78,79,80	3	41	30
DOE Diesel	78,79,80	3	15	7
Ford	79,80	2	13,497	112
J. D. Power	78,79	2	9,716	585
Ford	78	4	147	52
NFO	75-79	4	35	19
			53,250	

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[1] Data Type:

1 = Fleet Operations
2 = Owner Estimates
3 = Consumer Driving
4 = Test Measurements

TABLE 3-2

CRITERIA USED TO ELIMINATE BIASED AND INCONSISTENT DATA

Criteria	Data Eliminated
Outliers	2,230
Accumulated Mileage Under 2,000 miles	1,898
Data Source/Drive Cycle	
• Complaint letters	192
• Test measurements	6,693
Poor Record Keeping Behavior	1,136
Obsolete Vehicle Design Characteristics	15,862
TOTAL	28,011

As discussed in Section 2, the 404 report indicated that there is a definite relationship between odometer mileage, in-use fuel economy, and shortfall. Traditionally, vehicles with less than 4,000 miles have been excluded from consideration because EPA analysis of Emission Factor data indicated that most of the increase in fuel economy has occurred by the 4,000 mile point. EEA's examination of both the Ford and J. D. Power data indicates that the maximum increase in mpg occurs from 4,000 to 10,000 miles, the period associated with the first maintenance of the vehicle. The elimination of vehicles with less than 10,000 miles would significantly reduce the amount of data available for analysis. Therefore, it was decided to evaluate and, if necessary, account for the influence of odometer mileage, on shortfall in the dual-mode analysis. Due to the wide variation in in-use mpg during the break-in period, all data for vehicles with less than 2,000 miles were eliminated. This removed 1,898 data points from the analysis.

The DOE data base contains five major types of fuel economy data for in-use cars:

- On-road consumer driving
- On-road fleet driving
- On-road fuel economy test driving
- In-use dynamometer test
- Owner estimates of fuel economy.

At the outset, it was decided that dynamometer test results would not be used in the analysis even though they represent measurements of actual production cars. Earlier work[3/] has shown that there are significant differences between dynamometer test and in-use measurements of production car mpg. The on-road fuel economy test data (Motor Trend and Consumers Union) also were determined to be unrepresentative of in-use fuel economy[4/] and therefore were eliminated. One final category of DOE data were dropped, the consumer letters. These letters represent consumer complaints to both EPA and DOE about the fuel economy they were achieving in their cars. Clearly, the data contained in these letters represent the worst possible performance under in-use conditions and could bias the analysis results if included. The elimination of the above data sources from the DOE data reduced the data base by 6,806 measurements.

As discussed in the previous section, J. D. Power data include owner estimates of mpg and information about their record-keeping practices. While there are five codes for record-keeping practices, the mpg estimates actually are based on three categories of measurement: actual records, frequent or occasional checks, and perception. A review of the data indicated that the standard deviations around mean mpg values increased as record keeping became less accurate. The elimination of all data points except those associated with actual records would eliminate most of the non-Ford source data with estimates of percent urban and highway travel. Therefore, it was decided to eliminate only those data points, approximately 1,100, that were based on perception. It should be noted that the J. D. Power data are representative of how people perceive fuel economy. Most people do not keep detailed records, rather, they check their mpg on selected occasions and these occasional measurements form the bases of their perceptions.

The adjustment factors used in this study will be applied to future model year cars. The bulk of the measurements in the data base, however, detail the performance of cars containing technologies that will not be available in future model years. The analysis must not be biased by the performance of older technologies. Therefore, data used in the study were selected on the basis of vehicle design characteristics. Two simple criteria were employed: first, all 1977 and later cars were included; second, only MY 1975-1976 cars with the following design characteristics were selected:

- Diesels
- Front wheel drive
- Fuel injection
- Manual transmission
- Four cylinder engines
- Fuel economy of 25 mpg or greater.

Each of these criteria was applied to the data base separately, that is, all diesels regardless of drivetrain, transmission, number of cylinders or fuel economy were selected, all front wheel drive vehicles were selected, etc. Use of these criteria eliminated over 15,000 measurements of MY 1975-1976 cars from the analysis.

Table 3-3 summarizes the data sources and number of observations by model year retrieved from the original data base. The criteria used to eliminate data inconsistencies and biases reduced the size of the original data base by over 50 percent. Approximately 25,000 data points are available for the analysis. Unfortunately, the representation of MY 1980 cars is low relative to other model years and over 95 percent of the 1980 data covers the performance of Ford cars.

3.3 SUMMARY OF DATA BASE CHARACTERISTICS

The data base assembled for this study, though extensive, does not accurately represent either the sales distribution for the model years included or the technology characteristics of future cars. It is important to review the general fuel economy, manufacturer, and technology characteristics of the data in order to understand the potential limitations of the analysis.

TABLE 3-3

SUMMARY OF DATA RETAINED FOR ANALYSIS

Year	Total Number of Data Points	Total Number of Model/Engine Configurations
1975	202	48
1976	402	83
1977	3,339	144
1978	6,295	243
1979	10,862	237
1980	4,139	71
TOTAL	25,239	

Data Sources

- EPA Certification
- DuPont
- General Motors
- Mobil Oil
- Shell Oil
- TRW
- Maryland DOT
- Maine DOT
- EPA Emission Factor program
- Industrial Hydrocarbons
- J. Glass Leasing
- Texaco Oil
- EPA Portland
- AT&T
- Amoco Oil
- Wisconsin DOT
- Illinois DOT
- Runzheimer
- Tennessee DOT
- Libby Owens Ford
- Ford
- ARCO
- DOE Diesel
- J. D. Power
- NFO

Table 3-4 provides a listing of the average* EPA and on-road mpg for cars contained in the data base and the actual sales weighted average mpg for each of the model years. As can be seen, the EPA average mpg of the data contained in the data base is much higher than the average sales-weighted EPA value for MY's 1975-1976. This is due to the decision to retain only the more fuel-efficient technologies of these model years. With the exception of 1979, the average EPA value of MY's 1977-1980 closely approximates the sales weighted EPA value. There is no clear trend in the relation between EPA and in-use average mpg values represented in the data base.

Table 3-5 lists the distribution of data by manufacturer and model year. In order to make the comparison manageable, European and Japanese manufacturers have been organized into the two appropriate categories. It is immediately apparent that both categories (and particularly the Japanese) are under-represented in the data base. On the other hand, Ford is over represented among the domestic manufacturers, particularly in 1979 and 1980. Tables 3-6 through 3-11 detail the technology characteristics of the data. Rather than providing a discussion of the tables, the highlights are summarized below:

- The small car size classes are under-represented for MY's 1979 and 1980. Station wagons are over represented in MY's 1979 and 1980 (Table 3-6).
- Small engines, 4 cylinder or under 200 cid, are under-represented in all model years. Diesels are well-represented in terms of percentage sales for 1978 and 1979; however, the absolute number of data points is very small. There essentially are no diesel data for 1980 (Tables 3-7 and 3-9).
- The distribution of automatic and manual transmissions is representative for 1978 and later years (Table 3-8).
- Front wheel drive cars are well-represented by model years. The representation of individual manufacturers is, however, poor; GM's X-body is not well-represented (Table 3-11).

---

* Unless othewise noted, average refers to harmonic average.

TABLE 3-4

COMPARISON OF AVERAGE FUEL ECONOMY WEIGHTED FOR REPRESENTATION IN THE DATA BASE AND ACTUAL SALES

	Data Base		
Year	In-Use	EPA	Actual Sales-Weighted EPA*
1975	22.0	23.1	15.8
1976	20.0	25.1	17.5
1977	15.2	18.4	18.3
1978	16.8	20.5	19.9
1979	16.2	18.5	20.1
1980	17.8	21.9	22.4

---

* Light Duty Automotive Fuel Economy Trends Through 1981, J. A. Foster, J. D. Murrell, S. L. Loos, U.S. EPA, SAE #810386, February 23, 1981.

TABLE 3-5

```
                TABLE OF MANUFACTURERS BY MODEL YEARS
                       TABLE OF YEAR BY MANF
YEAR         MANF

FREQUENCY!
 PERCENT !
 ROW PCT !    AMC    Chrysler    Ford      GM     European  Japanese
 COL PCT !     1   !    2    !    3    !    4    !    5    !    6    !  TOTAL
---------+---------+---------+---------+---------+---------+---------+
 75      !      2  !      2  !     40  !     34  !     37  !     87  !    202
         !   0.01  !   0.01  !   0.16  !   0.13  !   0.15  !   0.34  !   0.80
         !   0.99  !   0.99  !  19.80  !  16.83  !  18.32  !  43.07  !
         !   0.32  !   0.08  !   0.32  !   0.42  !   7.79  !  10.62  !
---------+---------+---------+---------+---------+---------+---------+
 76      !     10  !     16  !     86  !    139  !     48  !    103  !    402
         !   0.04  !   0.06  !   0.34  !   0.55  !   0.19  !   0.41  !   1.59
         !   2.49  !   3.98  !  21.39  !  34.58  !  11.94  !  25.62  !
         !   1.61  !   0.62  !   0.68  !   1.71  !  10.11  !  12.58  !
---------+---------+---------+---------+---------+---------+---------+
 77      !    327  !    546  !    791  !   1584  !     15  !     76  !   3339
         !   1.30  !   2.16  !   3.13  !   6.28  !   0.06  !   0.30  !  13.23
         !   9.79  !  16.35  !  23.69  !  47.44  !   0.45  !   2.28  !
         !  52.57  !  21.04  !   6.27  !  19.53  !   3.16  !   9.28  !
---------+---------+---------+---------+---------+---------+---------+
 78      !     76  !   1055  !   1407  !   3282  !     85  !    390  !   6295
         !   0.30  !   4.18  !   5.57  !  13.00  !   0.34  !   1.55  !  24.94
         !   1.21  !  16.76  !  22.35  !  52.14  !   1.35  !   6.20  !
         !  12.22  !  40.66  !  11.15  !  40.46  !  17.89  !  47.62  !
---------+---------+---------+---------+---------+---------+---------+
 79      !    169  !    896  !   6316  !   3033  !    285  !    163  !  10862
         !   0.67  !   3.55  !  25.02  !  12.02  !   1.13  !   0.65  !  43.04
         !   1.56  !   8.25  !  58.15  !  27.92  !   2.62  !   1.50  !
         !  27.17  !  34.53  !  50.06  !  37.39  !  60.00  !  19.90  !
---------+---------+---------+---------+---------+---------+---------+
 80      !     38  !     80  !   3977  !     39  !      5  !      0  !   4139
         !   0.15  !   0.32  !  15.76  !   0.15  !   0.02  !   0.00  !  16.40
         !   0.92  !   1.93  !  96.09  !   0.94  !   0.12  !   0.00  !
         !   6.11  !   3.08  !  31.52  !   0.48  !   1.05  !   0.00  !
---------+---------+---------+---------+---------+---------+---------+
TOTAL         622      2595     12617      8111       475       819    25239
             2.46     10.28     49.99     32.14      1.88      3.24   100.00
```

TABLE 3-6

TABLE OF SIZE CLASSES BY MODEL YEARS

TABLE OF YEAR BY SIZE

YEAR / SIZE FREQUENCY PERCENT ROW PCT COL PCT	Mini 1	Subcompact 2	Compact 3	Mid Size 4	Large 5	Small Wagon 6	Mid Size Wagon 7	Large Wagon 8	TOTAL
75	114 0.45 56.44 9.00	64 0.25 31.68 1.54	7 0.03 3.47 0.24	4 0.02 1.98 0.05	4 0.02 1.98 0.06	9 0.04 4.46 2.03	0 0.00 0.00 0.00	0 0.00 0.00 0.00	202 0.80
76	252 1.00 62.69 19.89	88 0.35 21.89 2.12	14 0.06 3.48 0.47	2 0.01 0.50 0.02	12 0.05 2.99 0.19	21 0.08 5.22 4.73	13 0.05 3.23 0.94	0 0.00 0.00 0.00	402 1.59
77	162 0.64 4.85 12.79	778 3.08 23.30 18.77	707 2.80 21.17 23.87	792 3.14 23.72 9.83	808 3.20 24.20 12.95	43 0.17 1.29 9.68	42 0.17 1.26 3.04	7 0.03 0.21 0.94	3339 13.23
78	193 0.76 3.07 15.23	790 3.13 12.55 19.06	1139 4.51 18.09 38.45	2236 8.86 35.52 27.75	1448 5.74 23.00 23.21	204 0.81 3.24 45.95	155 0.61 2.46 11.22	130 0.52 2.07 17.45	6295 24.94
79	241 0.95 2.22 19.02	1564 6.20 14.40 37.74	897 3.55 8.26 30.28	4160 16.48 38.30 51.63	2638 10.45 24.29 42.29	118 0.47 1.09 26.58	774 3.07 7.13 56.01	470 1.86 4.33 63.09	10862 43.04
80	305 1.21 7.37 24.07	860 3.41 20.78 20.75	198 0.78 4.78 6.68	863 3.42 20.85 10.71	1328 5.26 32.09 21.29	49 0.19 1.18 11.04	398 1.58 9.62 28.80	138 0.55 3.33 18.52	4139 16.40
TOTAL	1267 5.02	4144 16.42	2962 11.74	8057 31.92	6238 24.72	444 1.76	1382 5.48	745 2.95	25239 100.00

TABLE 3-7

```
           TABLE OF ENGINE SIZE CATEGORIES BY MODEL YEARS
                      TABLE OF YEAR BY ESIZE (CID)
YEAR        ESIZE

FREQUENCY|
 PERCENT |
 ROW PCT |   <100     100-200   200-300   300-400    >400
 COL PCT |    1    |    2    |    3    |    4    |    5    |  TOTAL
---------+---------+---------+---------+---------+---------+
  75     |     87  |    101  |      8  |      0  |      6  |    202
         |   0.34  |   0.40  |   0.03  |   0.00  |   0.02  |   0.80
         |  43.07  |  50.00  |   3.96  |   0.00  |   2.97  |
         |   5.04  |   3.08  |   0.11  |   0.00  |   0.45  |
---------+---------+---------+---------+---------+---------+
  76     |    176  |    179  |     21  |     19  |      7  |    402
         |   0.70  |   0.71  |   0.08  |   0.08  |   0.03  |   1.59
         |  43.78  |  44.53  |   5.22  |   4.73  |   1.74  |
         |  10.20  |   5.46  |   0.28  |   0.17  |   0.52  |
---------+---------+---------+---------+---------+---------+
  77     |    102  |     95  |   1265  |   1796  |     81  |   3339
         |   0.40  |   0.38  |   5.01  |   7.12  |   0.32  |  13.23
         |   3.05  |   2.85  |  37.89  |  53.79  |   2.43  |
         |   5.91  |   2.90  |  16.61  |  15.92  |   6.04  |
---------+---------+---------+---------+---------+---------+
  78     |    523  |    744  |   2536  |   2317  |    175  |   6295
         |   2.07  |   2.95  |  10.05  |   9.18  |   0.69  |  24.94
         |   8.31  |  11.82  |  40.29  |  36.81  |   2.78  |
         |  30.30  |  22.70  |  33.29  |  20.54  |  13.06  |
---------+---------+---------+---------+---------+---------+
  79     |    647  |   1317  |   2640  |   5187  |   1071  |  10862
         |   2.56  |   5.22  |  10.46  |  20.55  |   4.24  |  43.04
         |   5.96  |  12.12  |  24.30  |  47.75  |   9.86  |
         |  37.49  |  40.19  |  34.66  |  45.99  |  79.93  |
---------+---------+---------+---------+---------+---------+
  80     |    191  |    841  |   1147  |   1960  |      0  |   4139
         |   0.76  |   3.33  |   4.54  |   7.77  |   0.00  |  16.40
         |   4.61  |  20.32  |  27.71  |  47.35  |   0.00  |
         |  11.07  |  25.66  |  15.06  |  17.38  |   0.00  |
---------+---------+---------+---------+---------+---------+
TOTAL        1726      3277      7617     11279      1340     25239
             6.84     12.98     30.18     44.69      5.31    100.00
```

TABLE 3-8

```
TABLE OF TRANSMISSION TYPES BY MODEL YEARS
          TABLE OF YEAR BY TRANS
YEAR           TRANS

FREQUENCY|
 PERCENT |
 ROW PCT | Automatic   Manual
 COL PCT |     1    |    2    |  TOTAL
---------+---------+---------+
  75     |      45 |     157 |     202
         |    0.18 |    0.62 |    0.80
         |   22.28 |   77.72 |
         |    0.21 |    4.69 |
---------+---------+---------+
  76     |     162 |     240 |     402
         |    0.64 |    0.95 |    1.59
         |   40.30 |   59.70 |
         |    0.74 |    7.17 |
---------+---------+---------+
  77     |    3218 |     121 |    3339
         |   12.75 |    0.48 |   13.23
         |   96.38 |    3.62 |
         |   14.70 |    3.62 |
---------+---------+---------+
  78     |    5631 |     664 |    6295
         |   22.31 |    2.63 |   24.94
         |   89.45 |   10.55 |
         |   25.72 |   19.85 |
---------+---------+---------+
  79     |    9520 |    1342 |   10862
         |   37.72 |    5.32 |   43.04
         |   87.65 |   12.35 |
         |   43.48 |   40.12 |
---------+---------+---------+
  80     |    3318 |     821 |    4139
         |   13.15 |    3.25 |   16.40
         |   80.16 |   19.84 |
         |   15.15 |   24.54 |
---------+---------+---------+
TOTAL        21894      3345     25239
             86.75     13.25    100.00
```

TABLE 3-9

```
                     TABLE OF CYLINDER COUNTS BY MODEL YEARS
                             TABLE OF YEAR BY FCYL
YEAR        FCYL

FREQUENCY!
 PERCENT !
 ROW PCT !
 COL PCT !ROT GAS !4CYL GAS!4CYL DES!6CYL GAS!6CYL DES!8CYL GAS!8CYL DES!  TOTAL
---------+--------+--------+--------+--------+--------+--------+--------+
  75     !      0 !    186 !      2 !      4 !      0 !     10 !      0 !    202
         !   0.00 !   0.74 !   0.01 !   0.02 !   0.00 !   0.04 !   0.00 !   0.80
         !   0.00 !  92.08 !   0.99 !   1.98 !   0.00 !   4.95 !   0.00 !
         !   0.00 !   4.30 !   1.06 !   0.06 !   0.00 !   0.07 !   0.00 !
---------+--------+--------+--------+--------+--------+--------+--------+
  76     !      0 !    354 !      1 !     21 !      0 !     26 !      0 !    402
         !   0.00 !   1.40 !   0.00 !   0.08 !   0.00 !   0.10 !   0.00 !   1.59
         !   0.00 !  88.06 !   0.25 !   5.22 !   0.00 !   6.47 !   0.00 !
         !   0.00 !   8.19 !   0.53 !   0.30 !   0.00 !   0.19 !   0.00 !
---------+--------+--------+--------+--------+--------+--------+--------+
  77     !      0 !    192 !      5 !   1241 !      0 !   1901 !      0 !   3339
         !   0.00 !   0.76 !   0.02 !   4.92 !   0.00 !   7.53 !   0.00 !  13.23
         !   0.00 !   5.75 !   0.15 !  37.17 !   0.00 !  56.93 !   0.00 !
         !   0.00 !   4.44 !   2.66 !  17.90 !   0.00 !  13.92 !   0.00 !
---------+--------+--------+--------+--------+--------+--------+--------+
  78     !      1 !   1061 !     21 !   2476 !      0 !   2701 !     35 !   6295
         !   0.00 !   4.20 !   0.08 !   9.81 !   0.00 !  10.70 !   0.14 !  24.94
         !   0.02 !  16.85 !   0.33 !  39.33 !   0.00 !  42.91 !   0.56 !
         ! 100.00 !  24.54 !  11.17 !  35.72 !   0.00 !  19.78 !  27.56 !
---------+--------+--------+--------+--------+--------+--------+--------+
  79     !      0 !   1514 !    154 !   2377 !     16 !   6713 !     88 !  10862
         !   0.00 !   6.00 !   0.61 !   9.42 !   0.06 !  26.60 !   0.35 !  43.04
         !   0.00 !  13.94 !   1.42 !  21.88 !   0.15 !  61.80 !   0.81 !
         !   0.00 !  35.02 !  81.91 !  34.29 ! 100.00 !  49.17 !  69.29 !
---------+--------+--------+--------+--------+--------+--------+--------+
  80     !      0 !   1016 !      5 !    813 !      0 !   2301 !      4 !   4139
         !   0.00 !   4.03 !   0.02 !   3.22 !   0.00 !   9.12 !   0.02 !  16.40
         !   0.00 !  24.55 !   0.12 !  19.64 !   0.00 !  55.59 !   0.10 !
         !   0.00 !  23.50 !   2.66 !  11.73 !   0.00 !  16.85 !   3.15 !
---------+--------+--------+--------+--------+--------+--------+--------+
TOTAL           1     4323      188     6932       16    13652      127    25239
             0.00    17.13     0.74    27.47     0.06    54.09     0.50   100.00
```

TABLE 3-10

```
              TABLE OF CARBURETER VENTURIS BY MODEL YEARS
                          TABLE OF YEAR BY FCARB
YEAR          FCARB

FREQUENCY|
 PERCENT |
 ROW PCT |
 COL PCT |1       |2       |3       |4       |FI GAS  |FI DIES |  TOTAL
---------+--------+--------+--------+--------+--------+--------+
  75     |      7 |    147 |     15 |      7 |     21 |      2 |    202
         |   0.03 |   0.58 |   0.06 |   0.03 |   0.10 |   0.01 |   0.80
         |   3.47 |  72.77 |   7.43 |   3.47 |  11.88 |   0.99 |
         |   0.16 |   0.77 |   9.09 |   0.86 |   4.53 |   0.60 |
---------+--------+--------+--------+--------+--------+--------+
  76     |     93 |    238 |     14 |      8 |     48 |      1 |    402
         |   0.37 |   0.94 |   0.06 |   0.03 |   0.19 |   0.00 |   1.59
         |  23.13 |  59.20 |   3.48 |   1.99 |  11.94 |   0.25 |
         |   2.10 |   1.25 |   8.48 |   0.98 |   9.06 |   0.30 |
---------+--------+--------+--------+--------+--------+--------+
  77     |    972 |   2120 |     10 |    215 |     17 |      5 |   3339
         |   3.85 |   8.40 |   0.04 |   0.85 |   0.07 |   0.02 |  13.23
         |  29.11 |  63.49 |   0.30 |   6.44 |   0.51 |   0.15 |
         |  21.98 |  11.17 |   6.06 |  26.28 |   3.21 |   1.51 |
---------+--------+--------+--------+--------+--------+--------+
  78     |   1226 |   4578 |     94 |    264 |     77 |     56 |   6295
         |   4.86 |  18.14 |   0.37 |   1.05 |   0.31 |   0.22 |  24.94
         |  19.48 |  72.72 |   1.49 |   4.19 |   1.22 |   0.89 |
         |  27.73 |  24.13 |  56.97 |  32.27 |  14.53 |  16.92 |
---------+--------+--------+--------+--------+--------+--------+
  79     |   1411 |   8715 |     32 |    323 |    123 |    258 |  10862
         |   5.59 |  34.53 |   0.13 |   1.28 |   0.49 |   1.02 |  43.04
         |  12.99 |  80.23 |   0.29 |   2.97 |   1.13 |   2.38 |
         |  31.91 |  45.93 |  19.39 |  39.49 |  23.21 |  77.95 |
---------+--------+--------+--------+--------+--------+--------+
  80     |    713 |   3175 |      0 |      1 |    241 |      9 |   4139
         |   2.82 |  12.58 |   0.00 |   0.00 |   0.95 |   0.04 |  16.40
         |  17.23 |  76.71 |   0.00 |   0.02 |   5.82 |   0.22 |
         |  16.12 |  16.73 |   0.00 |   0.12 |  45.47 |   2.72 |
---------+--------+--------+--------+--------+--------+--------+
TOTAL        4422    18973      165      818      530      331    25239
            17.52    75.17     0.65     3.24     2.10     1.31   100.00
```

TABLE 3-11

```
                TABLE OF DRIVE WHEELS BY MODEL YEARS
                       TABLE OF YEAR BY FFWD
YEAR          FFWD

FREQUENCY|
 PERCENT |
 ROW PCT |
 COL PCT |RWD GAS |RWD DIES|FWD GAS |FWD DIES|  TOTAL
---------+--------+--------+--------+--------+
  75     |    163 |      2 |     37 |      0 |    202
         |   0.65 |   0.01 |   0.15 |   0.00 |   0.80
         |  80.69 |   0.99 |  18.32 |   0.00 |
         |   0.69 |   0.79 |   3.20 |   0.00 |
---------+--------+--------+--------+--------+
  76     |    357 |      1 |     44 |      0 |    402
         |   1.41 |   0.00 |   0.17 |   0.00 |   1.59
         |  88.81 |   0.25 |  10.95 |   0.00 |
         |   1.50 |   0.39 |   3.80 |   0.00 |
---------+--------+--------+--------+--------+
  77     |   3303 |      2 |     31 |      3 |   3339
         |  13.09 |   0.01 |   0.12 |   0.01 |  13.23
         |  98.92 |   0.06 |   0.93 |   0.09 |
         |  13.91 |   0.79 |   2.68 |   3.90 |
---------+--------+--------+--------+--------+
  78     |   5912 |     39 |    327 |     17 |   6295
         |  23.42 |   0.15 |   1.30 |   0.07 |  24.94
         |  93.92 |   0.62 |   5.19 |   0.27 |
         |  24.89 |  15.35 |  28.24 |  22.08 |
---------+--------+--------+--------+--------+
  79     |  10079 |    206 |    525 |     52 |  10862
         |  39.93 |   0.82 |   2.08 |   0.21 |  43.04
         |  92.79 |   1.90 |   4.83 |   0.48 |
         |  42.44 |  81.10 |  45.34 |  67.53 |
---------+--------+--------+--------+--------+
  80     |   3936 |      4 |    194 |      5 |   4139
         |  15.59 |   0.02 |   0.77 |   0.02 |  16.40
         |  95.10 |   0.10 |   4.69 |   0.12 |
         |  16.57 |   1.57 |  16.75 |   6.49 |
---------+--------+--------+--------+--------+
TOTAL       23750      254     1158       77    25239
            94.10     1.01     4.59     0.31   100.00
```

In summary, there is a relatively poor representation of smaller fuel-efficient cars and alternative technologies within the data. This is borne out by the lack of foreign manufacturer and small engine data.

FOOTNOTES FOR SECTION 3

1/ McNutt, Barry et al. 1978. Comparison of EPA and In-Use Fuel Economy of 1974-1978 Automobiles. SAE Paper 780037. February.

2/ Ibid.

3/ McNutt, Barry and Dulla, Robert. 1979. "On-Road Fuel Economy Trends and Imports." Presentation at TRB Annual Meeting. Washington, D.C. January.

4/ Ibid.

4. ODOMETER ANALYSIS

4.1 INTRODUCTION

This section examines the dependence of on-road fuel economy on accumulated mileage (or odometer). Previous work[1/] in this area showed that new vehicle fuel economy increases at a logarithmic rate over at least 50,000 miles of driving. The prior work often used durability data collected as part of EPA certification programs. Under these conditions, the odometer dependence of fuel economy generally was understood to result from engine and drivetrain break-in.

The in-use vehicle data bases of the present study show that the change in fuel economy is greatest over the interval 4,000 to 10,000 miles with only a weak odometer dependence outside the range. Because the vehicles are operated and maintained by consumers, other factors besides the break-in period will influence on-road fuel economy. These include:

- Changing conditions of vehicle use with increasing age
- Departure of field maintenance practices during warranty from manufacturer specifications
- Owner maintenance practices after the warranty period.

This situation differs from previous work and results in different conclusions.

Although the odometer dependence is relatively modest -- typically several percent of the 4,000 mile fuel economy -- development of fuel economy adjustment factors must consider the effect. First, the existence of this dependence means that fuel economy shortfall is itself a function of odometer. In particular, the relatively low-mileage vehicles of the in-use data base on late-model cars will tend toward higher shortfall. If the odometer effect is large, then correcting in-use data to a common odometer value standardizes the meaning of shortfall.

Second, the existing data sets span relatively wide ranges of odometer. Oil company and fleet data, for example, are drawn from vehicles with accumulated mileage ranging from 4,000 miles to 20,000 miles. Other sources have a much lower average odometer and include many vehicles below 4,000 miles. Again, if the odometer dependence is large, then standardizing to a common odometer value is essential to allow pooling of data sources without introducing bias, while using the available data to the greatest extent possible.

This analysis shows that for in-use cars (and on-road fuel economy), the odometer dependence follows approximately an S-shaped curve. While its general analytic form is not quantified here, the curve shape and magnitude indicate, at most, a limited need to introduce odometer corrections into the in-use data base. Following the discussion of analysis methodology and results, Section 4.4 indicates the circumstances requiring odometer corrections and the factors employed.

4.2 METHODOLOGY

Previous analyses of the odometer dependence have been based on dynamometer fuel economy data collected under EPA certification and surveillance testing. In these data, measurement techniques are uniform across the sample, thereby eleminating from the odometer effect any factors of changing vehicle use with increasing age. In addition, conditions of mileage accumulation are uniform in the certification (or durability) data, which also include measured or estimated 4,000 mile fuel economies. With one exception, the on-road data bases are substantially different and somewhat less appropriate to this analysis. In all cases, the on-road fuel economy data incorporate elements of vehicle use patterns which can influence fuel economy levels.

The analysis first examines odometer trends in the on-road data from the National Family Opinion Poll (NFO) Gasoline Diary Panel. The fuel economy data from this consumer panel survey are drawn from fuel purchase records (not owner estimates) and form relatively long time series of vehicle use. The data are then very appropriate to the study of odometer trends and provide the best available data base for this analysis.

As a second step, the analysis examines odometer trends in the J.D. Power/DOE Survey data base. The Power survey is characteristic of most on-road data bases in that it provides single observations (or "snapshots") of each vehicle's fuel economy. The analysis of odometer trends is therefore more difficult and less precise. However, the Power data are important to the two-mode correction factor analysis of Section 6 and are included here to validate conclusions of the NFO study.

4.2.1 NFO Data Base

The analytic technique applied in previous work is a regression of the (normalized) fuel economy data against the logarithm of odometer in the following form:

$$\frac{\mathrm{MPG}\ (x)}{\mathrm{MPG}(4k)} = a + b \ \log(\mathrm{odometer}) \qquad (1)$$

Here, the normalized fuel economy is expressed as a fraction (or multiple) of the measured 4,000 mile fuel economy. The normalization achieves two results: 1) it permits pooling of data from vehicles of greatly different fuel economy levels and 2) it isolates the quantity of interest, which is the fuel economy change relative to a common (baseline) odometer.

This technique is appropriate for analysis of the on-road data from NFO. In this data base, the time series of fuel purchases recorded by the participating households permit the calculation of fuel economy over the mileage intervals between fuel purchases. Much of the development work with this data base has, in fact, focused on validating the internal consistency of each time series and construction of unbiased statistical techniques for the fuel economy calculations.[2-3/] The NFO analysis is based on a subset of MY 1978 through 1980 vehicles (including light trucks and some diesel cars). These vehicles entered the survey panel before accumulating 4,000 miles and therefore present a baseline fuel economy for the normalization step.

After the data are matched to eliminate seasonal trends in fuel economy, as detailed in the analysis, the NFO study examines fuel economy trends over several odometer ranges. In practice, the regression analysis does not use equation (1). Instead, a modified one-parameter model is employed as shown in equation (2):

$$R = b \log_e (x) \qquad (2)$$

where

$$R = \frac{\text{MPG }(x)}{\text{MPG}(4k)} - 1$$

$$x = (\text{odometer})/4000$$

This form is algebraically equivalent to equation (1) but is specified to pass through unity at the baseline (4,000) odometer. To facilitate comparison with previous work, the intercept of the equation (1) form has been calculated and is cited in presentation of results.

4.2.2 J.D. Power Data Base

The analysis techniques must be modified for other on-road fuel economy data bases. Because the Power data provide only single observations per vehicle in the sample, normalization factors must be derived from the data base as a whole. The baseline fuel economies, therefore, are not specific to each vehicle and cannot account for substantial differences in fuel economy level or vehicle use patterns within the sample.

The analysis of this data base must first correct for any factors (except odometer) that influence the fuel economy level of vehicles at high and low mileage. The primary concern is whether heavier vehicles are used more or less intensively than others and therefore tend to cluster at higher or lower odometers. When any differential use effects are removed (if indeed present), the remaining odometer-related variation in fuel economy can be attributed to the basic odometer relationship.

Following the correction of sample biases, normalization factors may be derived from regression analysis using the following model:

$$\text{MPG} = a + b \log_e(\text{odometer}) \qquad (3)$$

The coeffecients are determined separately for each of the model year samples (MY 1978 and MY 1979) present in the data; the normalization factor for each sample is the 4,000 mile fuel economy predicted by the regression equations. These baseline fuel economies represent the data base averages at 4,000 miles after correction for any differences in vehicle use.

The methodology of the second odometer analysis therefore involves two additional steps before trends in fuel economy can be examined:

- Investigation of sample homogeneity, particularly with respect to vehicle use
- Derivation of normalizing factors from the data base fuel economy at 4,000 miles.

Following these steps, the Power study employs the one-parameter model of equation (2) to determine the variation in fuel economy over several odometer ranges. The following section treats the two odometer analyses in turn, with primary focus upon the trends observed in the NFO data. Section 4.4 indicates how odometer corrections are used in the correction factor analyses of later sections and also presents a brief critique of these results.

4.3 ANALYSIS OF ODOMETER TRENDS

4.3.1 NFO Data Base

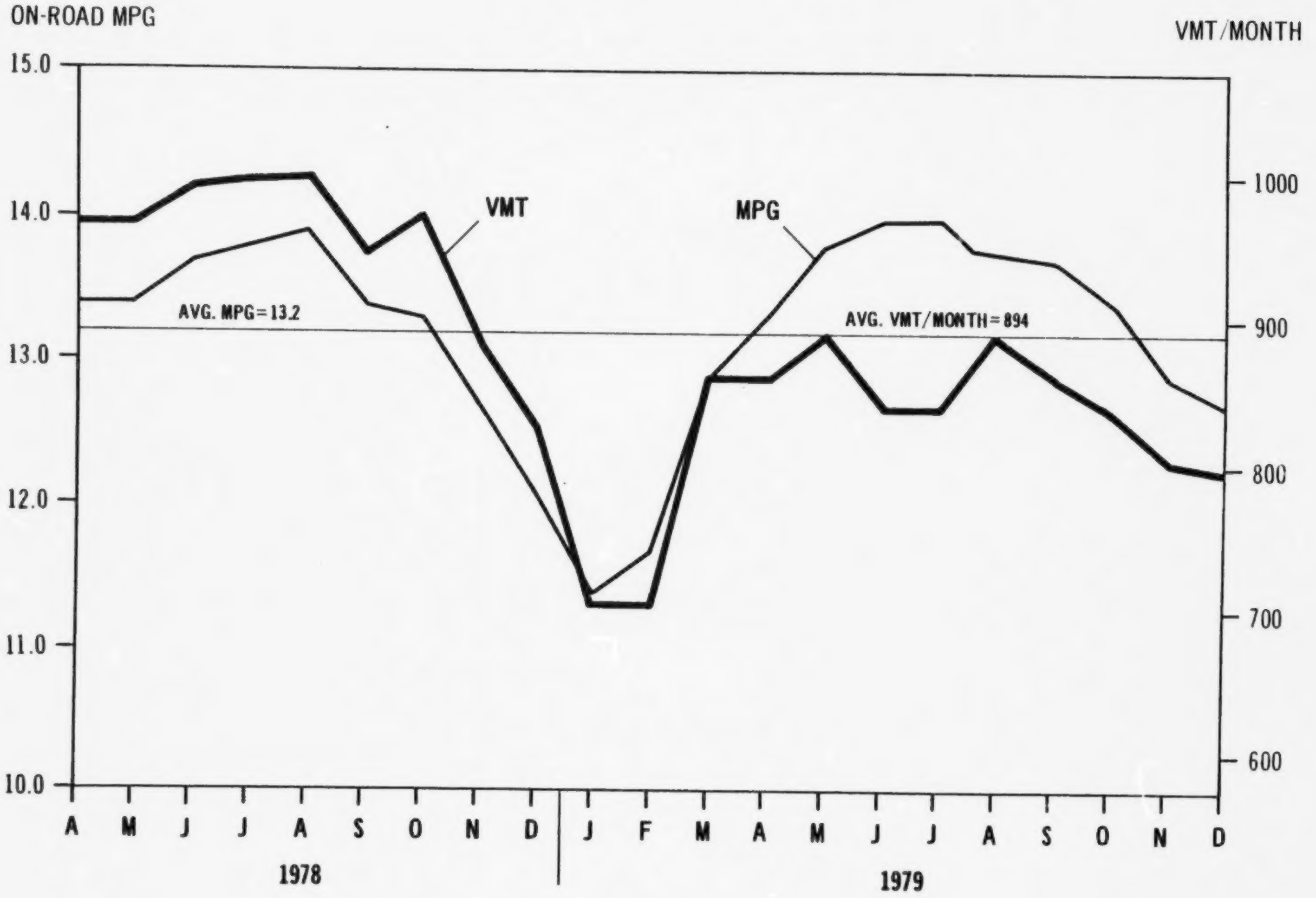
The analysis presented below is based on the 709 MY 1978-1980 cars and light trucks which entered the NFO panel survey before 4,000 miles. For these vehicles, the baseline fuel economy for normalization is defined as the estimated fuel economy over the purchase interval which spans 4,000 miles. The data of the analysis are observed fuel economies (between purchases) at lower and higher odometers, normalized by the 4,000 mile figure. It should be remembered, however, that each data point represents the comparison of fuel economies at two separate odometers.

As noted in the introduction, several factors influence the odometer dependence of on-road fuel economy. In particular, the effects of vehicle use and owner maintenance are included in the aggregate odometer dependence; this analysis does not attempt to separate or to control for either component. Rather, the regional and demographic balance of the NFO consumer panel assures that owner-related elements are represented in proportion to their national prevalence. The primary concern is the potential for seasonal bias in the subset of data analyzed.

4.3.1.1 Seasonal Trends

In general, seasonal trends will be present for any vehicle that remains in the survey panel for less than a full year. As shown in Figure 4-1, the combined effects of weather conditions and seasonal travel patterns cause very large changes in fuel economy. The figure illustrates these trends by showing monthly fuel economy and travel for a constant sample of 494 cars over the 21 months of the NFO data. The seasonal effect is relatively large compared to an odometer dependence of a few percent, so that the data used here must be free from any seasonal bias.

FIGURE 4–1
EFFECTS OF SEASONS AND TRAVEL PATTERNS ON MPG
1975–1978 MODEL YEARS
GASOLINE POWERED CARS



The seasonal trends will introduce substantial bias (rather than additional variability) when the normalizing fuel economy is taken from an extreme (highest or lowest) fuel economy season and compared with an incomplete annual cycle of fuel economy. For example, a vehicle reaching 4,000 miles during January will show an upward trend in fuel economy at higher odometers as a result of seasons alone. Conversely, the seasonal trends will mask any odometer dependence for vehicles entering during the summer and accumulating mileage during the months of declining fuel economy. A preliminary analysis of odometer trends demonstrated a significant seasonal bias and has, therefore, led to seasonal matching of the data.

The matching retains fuel economy pairs (at 4,000 and another odometer) that are free of differential seasonal effects. This means that 1) both the month of normalizing fuel economy and of the other odometer point must be unbiased relative to the annual average or 2), if biased, both must show comparable, and therefore offsetting, effects. In practice, data were retained for analysis when the fuel economy pairs met one of the conditions summarized in Table 4-1. While the requirements for seasonal matching reduce the sample size available for the analysis, they prohibit data points that are strongly biased due to seasons -- primarily summer versus winter comparisons.

4.3.1.2 Results

As noted in the methodology, the regression analysis uses a model constrained to pass through unity at 4,000 miles. The results cited below are presented as the intercept and slope of the equivalent log-linear function.

The most striking result of the odometer analysis is that the odometer slope (in log-space) is clearly a function of the data set's odometer range. As shown in Table 4-2, the odometer dependence is strongest over

TABLE 4-1

SEASONAL MATCHING OF THE NFO DATA

Condition 1:

Accept 4,000 mile and other odometer points from the same or neighboring months.

- Results in odometer points spaced by 1 month or by 11 to 13 months.
- Example: For a vehicle reaching 4,000 miles in June 1978, data will be accepted for the other odometer point during May through July 1978 and May through July 1979.

Condition 2:

Accept 4,000 mile and other odometer point drawn from the periods March through May or September through November.

- Results in odometer points spaced by 4 to 8, 10 to 14, or 16 to 20 months.
- Example: For a vehicle reaching 4,000 miles in May 1978, data will be accepted for other odometer points during
  - September through November 1978
  - March through May 1979
  - September through November 1979.

TABLE 4-2

SUMMARY OF ODOMETER REGRESSIONS[a/]

(NFO Data Base)

Equation: $\frac{MPG(x)}{MPG(4k)} = A + B \log_e (\text{odometer})$

Odometer Range	Average Odometer	N	R^2	A (Intercept)	(SE)	B (LOG_e Slope)	(SE)
2k - 25k	7540	15,348	.0033	.800	.028	.0241	.0034
2k - 10k	4770	11,593	.0014	.738	.064	.0316	.0077
4k - 10k	5760	6,717	.0037	.649	.071	.0423	.0085
10k - 25k[b/]	16210	3,699	.0002	1.006	.039	.0227	.0282

[a/] Analysis based on seasonally-matched data (see Table 4-1) from 709 model year 1978-1980 vehicles.

[b/] Regression line for interval 10k - 25k is not constrained to pass through unity at 4,000 miles. Sample includes only vehicles present in the survey panel at 4,000 miles and continuing in operation past 10,000 miles. Slope is not statistically different from zero.

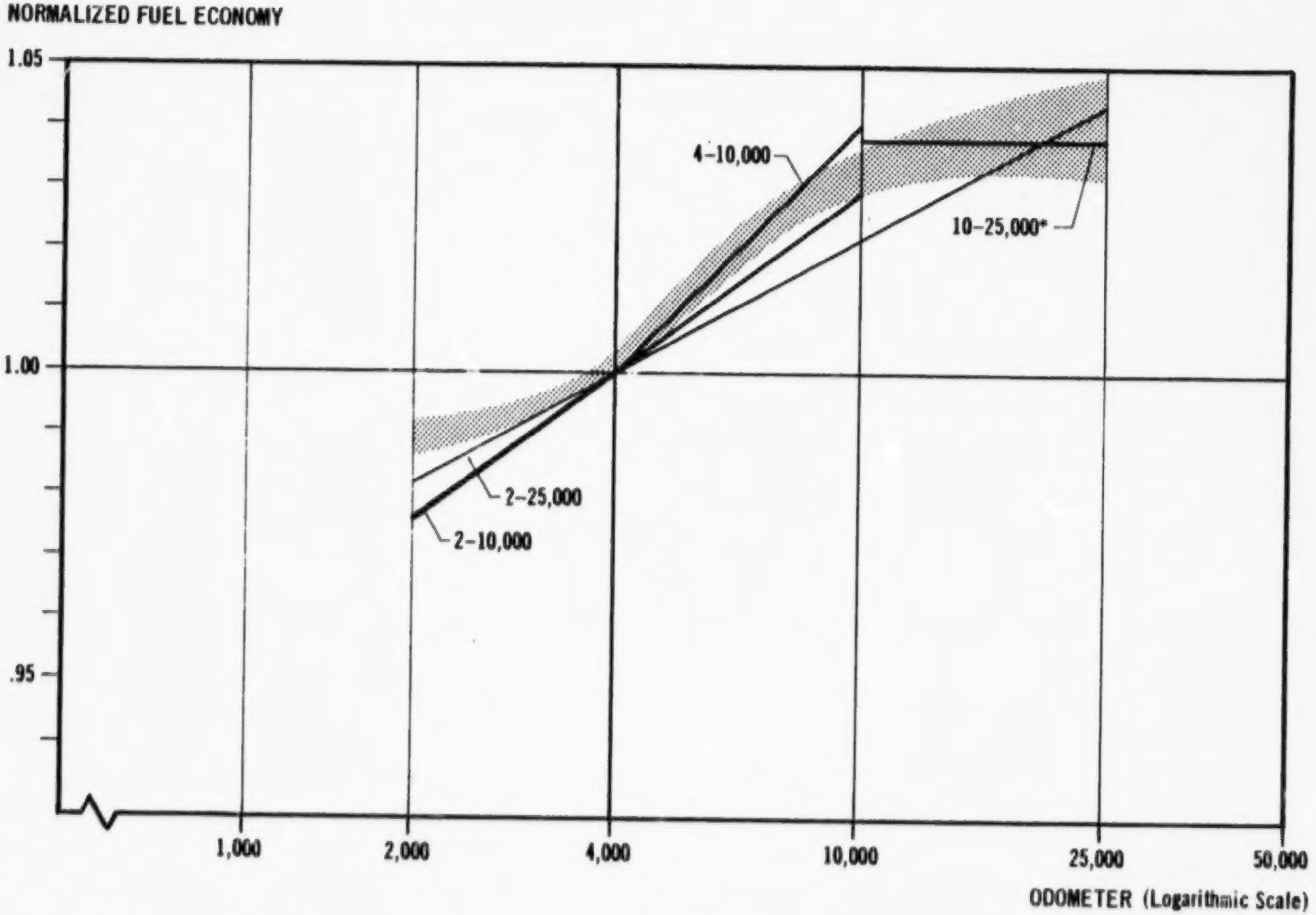
the interval 4,000 to 10,000 miles. When data points are included at lower or higher odometers, the regression fit produces a smaller slope. These results strongly imply that the underlying relationship is not a simple function of the odometer logarithm and suggest that its shape is closer to an S-curve. In particular, the fuel economies above 10,000 miles (and extending to the effective limit of the sample at 25,000 miles) are statistically independent of odometer. The data in this region also show a great increase in variability.

Calculation of mean values for the normalized fuel economies within 1,000 mile odometer ranges further substantiates these conclusions. Between 2,000 and 4,000 miles, fuel economy is not statistically different from the baseline (4,000 mile) value and shows at most a one percent average discounting for the 2,000 mile range. Over the 4,000 to 10,000 mile interval, fuel economy increases sharply, with an average increase of 2.0 percent in the 6,000 mile range and 3.4 percent at 10,000 miles. The dependence also is apparently greatest between 5,000 and 8,000 miles. Beyond 10,000 miles, no trend is discernable in the data, which show an average of 3.8 percent increase. These results are summarized in Figure 4-2, which illustrates the general trend with odometer and the regression lines found for the several odometer ranges.

4.3.1.3 Discussion

Figure 4-2 demonstrates clearly why regression lines which are fit over varying odometer ranges produce systematically different slopes. Only in the relatively narrow 4,000 to 10,000 mile interval does the regression line fit the data well. Over all other intervals, the linear model departs significantly from the curvilinear trends and is leveraged to lower slopes by the tails of the S-curve. As a result, data sets will exhibit different linear fits when they span differing ranges or are clustered at different odometers -- even if the underlying odometer relationship is identical.

FIGURE 4–2
ODOMETER TRENDS IN ON-ROAD FUEL ECONOMY
NFO DATA BASE



* Mean value of normalized fuel economy. Slope of regression line not statistically significant.

While the empirical conclusions are straightforward, an understanding of the dominant physical processes is more rudimentary. The leveling off of the odometer curve above 10,000 miles appears to be associated with the varying conditions of use and maintenance when vehicles leave warranty coverage. This also is supported by the observed increase in data variability. Effects below 10,000 miles are less well understood.

Discussions of these results with an industry source suggest that the strong dependence between 4,000 and 10,000 miles may be associated with field maintenance practices during break-in and the occurrence of major tune-ups at 6,000 to 7,500 miles. In particular, this source believes that true break-in processes within the engine and drivetrain are substantially complete by 1,000 miles, accounting for the weak odometer dependence below 4,000 miles. While the hypothesis remains speculative, it may occur that dealer practices lead to setting new vehicles rich for good driveability. The associated fuel economy loss then is corrected at the first major tune-up, with a resulting improvement that appears distributed over the interval 5,000 to 8,000 miles.

Regardless of interpretation, the NFO study indicates that the odometer dependence reaches a plateau above 10,000 miles and introduces approximately a five percent differential in fuel economy between low- and high-mileage vehicles. Under these circumstances, correction of in-use data to a common odometer value becomes important only when aggregating data sets of vehicles with large differences in average accumulated mileage.

4.3.2 J.D. Power/DOE Surveys

As noted in the discussion of methodology, the Power data base is not well-suited to the analysis of odometer relationships, because the data consist of single observations per vehicle. As a result, the data base offers no direct measure of each vehicle's change in fuel economy with increasing mileage relative to a common odometer value. The regression analysis therefore must infer the underlying odometer dependence.

Conceptually, the analysis technique examines average on-road fuel economies as function of odometer. After correcting for any factors, except odometer, which influence the fuel economy level of low- and high-mileage vehicles, the remaining systematic variation is a result of the odometer relationship. The primary source of sample bias is associated with the use patterns of heavy vehicles.

Table 4-3 summarizes three methods for investigating whether differential use effects are present in the Power data. Models 1 and 2 examine vehicle use as functions of vehicle weight, while Model 3 considers whether the EPA rating of the sample is independent of odometer. Models 2 and 3 indicate that heavier vehicles in the MY78 sample are used less intensively (1.3 miles per day less per 1000 pounds) and tend toward lower odometers. However, the effect of weight is not statistically significant in the MY 1979 sample. The differential use effects are clearly small; yet, the significance of the regression models for MY 1978 indicates that correction for vehicle weight is appropriate.

Earlier work by EEA in fuel economy modeling[4/] showed that vehicle weight is the single best predictor of fuel economy. Weight is highly correlated with fuel consumption rates and also with the other major vehicle design parameters influencing fuel consumption. Table 4-4 shows a simple regression model used to standardize the Power data to a common inertia weight. The standardization adjusts upward the fuel economy of heavy vehicles (and downward for light vehicles) to eliminate the small bias present in the Power data. As shown in the table, the on-road data of each model year sample is corrected using the model year-specific fuel consumption regression model.

TABLE 4-3

REGRESSION ANALYSIS FOR DIFFERENTIAL USE EFFECTS
(J.D. Power/DOE Surveys)

MODEL 1: Odometer = a + b (Inertia weight)

MY	N	R^2	a	(SE)	b	(SE)
78	3646	.0008	10526	(513)	-.201[a/]	(.135)
79	3603	.0003	7033	(581)	+.035[a/]	(.147)

MODEL 2: Average Miles per Day = a + b (Inertia weight)

MY	N	R^2	a	(SE)	b	(SE)
78	3646	.0013	47.5	(2.2)	-.0013	(.0006)
79	3603	.00001	34.6	(2.5)	+.0001[a/]	(.0006)

MODEL 3: EPA Rating (55/45) = a + b (Odometer)

MY	N	R^2	a	(SE)	b	(SE)
78	3332	.0017	21.56	(.163)	+.0370	(.0157)
79	3575	.0002	20.22	(.115)	-.0145[a/]	(.0186)

[a/] Denotes coefficient is not significant at the 0.05 level.

LEGEND: (SE) denotes the standard error of estimate for regression coefficients.

DATA SET: Gasoline-powered vehicles from the J.D. Power/DOE Surveys

TABLE 4-4

STANDARDIZATION OF POWER DATA FOR VEHICLE WEIGHT

REGRESSION MODEL FOR ON-ROAD FUEL CONSUMPTION RATES

$$FC = \frac{1}{MPG} = a + b \text{ (Inertia weight)}$$

MY	N	R^2	a	(SE)	b	(SE)
78	3127	.382	.01187	(.00104)	.01195	(.00027)
79	3249	.283	.01152	(.00139)	.01260	(.00035)

NOTE: Inertia weight in units of 1000 pounds

STANDARDIZATION PROCEDURE

$$\text{(MY 78)} \qquad \frac{1}{MPG'} = \frac{1}{MPG} + .01950\ (3.800 - IWT)$$

$$\text{(MY 79)} \qquad \frac{1}{MPG'} = \frac{1}{MPG} + .01260\ (3.800 - IWT)$$

where:

MPG is observed fuel economy at weight IWT
MPG' is fuel economy corrected to 3800 pounds

RESULTS

	UNCORRECTED MEAN VALUES				CORRECTED MEAN	
MY	MPG	(SE)	IWT	(SE)	MPG'	(SE)
78	17.75	(.10)	3734	(14)	17.46	(.07)
79	16.56	(.09)	3880	(11)	16.83	(.07)
78/79	16.56	(.07)	3810	(9)	17.13	(.05)

LEGEND: (SE) denotes standard error.

Following this adjustment of the fuel economy data, the remaining variation with respect to odometer is analyzed with the non-normalized regression model shown in Table 4-5. The predicted fuel economies at 4,000 miles become normalizing factors for the weight-corrected data. The normalized fuel economies then may be analyzed with the one-parameter regression model which forces the log-linear function through unity at 4,000 miles. The use of normalization and a second regression step also permits pooling of data from the two model-year group.

Table 4-6 summarizes the regression analysis performed on the normalized Power data. As observed in the NFO analysis, the log-linear slope is directly related to the odometer range of the data. Again, the strongest dependence is found over the interval 4,000 to 10,000 miles, with systematically lower slopes as the range is extended. Over 4,000 to 10,000 miles, the Power analysis predicts fuel economy increases of 3.7 to 5.5 percent, depending upon model year. The comparable analysis using NFO data predicts a 3.9 percent increase.

These results indicate substantial agreement between the data bases in terms of the qualitative nature of the odometer curve and the approximate magnitude of the dependence. In addition, the model year differences observed in the Powers data can be related directly to the odometer intervals and clustering of the two samples. The 1979 vehicles were purchased in October 1978 and their owners surveyed in Spring 1979. Because these vehicles were on the road for a shorter period of time, and primarily for winter season driving, compared to the 1978 sample (purchased in August 1978 and surveyed in the Spring), the 1979 sample has a lower average odometer and fewer vehicles accumulating 10,000 miles or more. The regression analysis for 1979 is therefore more strongly influenced by vehicles in the odometer region of greatest fuel economy change and can be expected to show greater regression slopes.

TABLE 4-5

NORMALIZATION OF POWER DATA

REGRESSION ANALYSIS

$$MPG' = a + b \log_e (\text{Odometer})$$

MY	N	R^2	a	(SE)	b	(SE)
78	3045	.0083	13.66	(0.91)	0.515	(0.103)
79	3177	.0174	11.65	(0.80)	0.724	(0.096)

NORMALIZING FACTORS

MY	PREDICTED FUEL ECONOMY AT 4,000 MILES
78	17.93 mpg
79	17.65 mpg

NORMALIZATION PROCESS

(MY 78) $$\frac{MPG'}{MPG4k} = \frac{MPG'}{17.93}$$

(MY 79) $$\frac{MPG'}{MPG4k} = \frac{MPG'}{17.65}$$

NOTE: Analysis based on fuel economy data corrected to 3800 pounds inertia weight.

TABLE 4-6

SUMMARY OF ODOMETER REGRESSIONS
(J.D. Power Data Base)

Equation: $\frac{MPG}{MPG(4k)} = A + B \log_e (\text{odometer})$

Odometer Range	Average Odometer (miles)	Model Year(s)	N	R^2	A (Intercept)	(SE)	B (LOG_e Slope)	(SE)
ALL	8500	1979	3045	.0144	.762	.036	.0287	.0043
ALL	4820	1979	3177	.0174	.660	.045	.0410	.0054
ALL	6500	1978/1979	6222	.0155	.721	.028	.0336	.0034
2k - 25k	8010	1978	2845	.0157	.722	.041	.0335	.0050
2k - 25k	5260	1979	2686	.0137	.589	.067	.0496	.0081
2k - 25k	6660	1978/1979	5531	.0142	.685	.035	.0380	.0043
4k - 10k	6830	1978	1664	.0015	.668	.076	.0400	.0091
4k - 10k	6100	1979	1486	.0180	.504	.095	.0598	.0115
4k - 10k	6490	1978/1979	3150	.0139	.607	.059	.0474	.0071

4.4 CRITIQUE OF THE RESULTS

On the basis of this analysis, EEA concludes that odometer corrections are not a crucial element for the present study of on-road fuel economy. The two-mode analysis of Section 6 is based on the Power data, without standardizing to a common odometer, so that the resulting adjustment factors represent approximately a 6,500-mile shortfall, the mean odometer of the data set. The odometer bias is on the order of two to three percent, compared to either a 4,000 mile or high-mileage shortfall. This difference is well within the uncertainty implicit in the two-mode analysis and does not justfiy instituting odometer corrections.

On the other hand, the one-mode analysis of Section 5 aggregates DOE fleet data sources with lower odometer consumer data. Because the low to high odometer differential can be as large as four to five percent, EEA has adopted a simplified odometer correction for the low-mileage data. The correction factors adjust the consumer data (the smaller portion of data available for the one-mode analysis) to the high mileage plateau, which should be characteristic of the higher odometer vehicles in the fleet data. Table 4-7 summarizes the adjustment factors employed for this purpose.

While the foregoing odometer analysis has established the fundamental shape and magnitude of the effect for on-road fuel economy, it is not conclusive in three areas:

- Quantifying the odometer curve in terms of an appropriate analytic expression
- Exploring the trends beyond 25,000 miles
- Revealing the physical or behavioral processes occuring during 4,000 to 10,000 miles.

The purpose of the following critique is to briefly examine these points.

TABLE 4-7

CORRECTION OF LOW-MILEAGE ON-ROAD DATA FOR THE ONE-MODE ADJUSTMENT FACTOR ANALYSIS

Odometer Range	Correction to High-Mileage Plateau
2000 - 3000	+5 percent
3000 - 5000	+4 percent
5000 - 7000	+2.5 percent
7000 and above	no correction

Data Sources Affected

J.D. Power/DOE Surveys

Ford Surveys

NFO Panel Survey

In general, regression analysis is an inadequate tool to determine analytic forms for poorly understood relationships, because the choice of regression model largely determines the trends seen as the analysis is extrapolated beyond existing data. In the context of the odometer analysis, it is not known which mathematical model the on-road data follow within the range of 2,000 to 25,000 miles or which trends will be seen at higher mileage.

During the present study, several regression models were explored to simulate the S-curve found in the NFO data. All have failed because the coefficients of the multi-parameter models were statistically not significant or because they did not reproduce the strong curvature within the 4,000 to 10,000 mile range. These models employed fractional powers of the logarithmic odometer value (with appropriate sign conventions) in addition to the over-all linear trend and did achieve the characteristic flattening seen in the empirical relation. These models introduce a downturn in fuel economy at sufficiently high mileage and will diverge toward unreasonable values in the limit.

Specification of an analytical form for the on-road odometer dependence will require further work in following the fuel economy trend to higher mileage. This is limited at present by the length of time series present in the NFO data. Among the vehicles present in the survey panel at 4,000 miles, only a very small sample remain in the survey for a period sufficient to accumulate more than 25,000 miles. While these vehicles show a downturn in fuel economy from the 10,000 to 25,000 mile plateau, the trend may result from characteristics of the specific owners and cannot be thought representative of a larger population.

Finally, the causal factors for the 4,000 to 10,000 mile effects require further exploration. While the discussion of the NFO analysis offered a behavioral explanation related to field maintenance practices, other work[5/] has shown effects similar in magnitude on a vehicle sample not susceptible to the effects of maintenance. The other work involved prototype vehicles delivered to the EPA for certification testing. The existence of a strong odometer dependence in these vehicles suggests, therefore, a physical process associated with the engine or drivetrain. Accordingly, a study that identifies the reason for the odometer dependence of these vehicles will help reveal the mileage interval in which in-use maintenance begins to influence on-road fuel economy.

FOOTNOTES FOR SECTION 4

1/ U.S. Environmental Protection Agency. 1980. Passenger Car Fuel Economy: EPA Road, EPA 460/3-80-010. Ann Arbor, Michigan: EPA, January.

2/ Energy and Environmental Analysis, Inc. 1981. "Vehicle Purchase and Use Data Matrices: N.F.O. Gasoline Diary Panel" (draft final report). Prepared for the U.S. Department of Energy. Arlington, Virginia: EEA, April.

3/ Falcon Research and Development. 1980. "Computation of Vehicle Fuel Economy," Falcon Reserch and Development. Prepared for Energy and Environmental Analysis, Inc., August.

4/ Energy and Environmental Analysis, Inc. 1980. Technical Analysis of the Light Duty Truck Fuel Economy Standards for 1985 Model Year. Prepared for U.S. DOE, Contract No. DE-AC01-79PE-70032. Arlington, Virginia: EEA, May 9.

5/ U.S. Environmental Protection Agency. 1981. Effect of Vehicle Mileage Accumulation on Tested Fuel Economy (Draft Report). EPA, AA-CPSB-81-03. Ann Arbor, Michigan: EPA, February.

5. COMBINED MODE ANALYSIS

5.1 INTRODUCTION

By law, both the DOE/EPA Gas Mileage Guide and the fuel economy label have been required to display separate mpg estimates for city and highway driving schedules. In 1976, the combined rating was added to the label and Guide on EPA's initiative. This practice changed in 1979 because the highway and composite estimates were recognized as not corresponding well with consumer experience and were discrediting the fuel economy information program. Therefore, EPA decided to eliminate the highway and composite values from the label and the guide until a more accurate measure of mpg could be developed for the consumer. EPA currently provides fuel economy values based only on the "stop-and-go" driving of the city test cycle. Use of the highway value in advertising has continued.

This section examines the shortfall for composite EPA fuel economy values. The purpose of the analysis is to develop adjustment factors for a one number mpg information system based on the EPA combined cycle value instead of the city value currently in use. EPA believes[1/] that, if a single value system is to be employed, it is preferable to relate it to the composite value because it provides a link with the information used in CAFE compliance and gas guzzler programs.

In support of developing composite adjustment factors, this section examines the sensitivity of alternative fuel efficient technologies to shortfall. Also examined is the sensitivity of these technologies to changes in test procedure protocol.

5.2 METHODOLOGY

There are two components to the methodology presented in this section: 1) the definition of alternative technologies to be examined for differential shortfall behavior and the specification of consistent measures of shortfall and 2) the definition of the proper space (e.g., mpg or 1/mpg) for regression analysis.

5.2.1 Technology Specification

Section 2 presented a number of engineering reasons which suggest that alternative technologies are not as sensitive to shortfall as are traditional technologies. For the purposes of this analysis, traditional technologies are defined to include carburetted, rear-wheel drive vehicles. The characteristics of alternative technologies that distinguish them from the traditional technologies include the following:

- Lighter weight (downsizing, material substitution)
- Alternative Fuel Systems (fuel injection, feedback carburetors)
- Smaller Engine Size (lower average CID and cylinder counts)
- New Transmissions (manuals with overdrive, automatics with torque convertors and lockup clutches)
- New Drive Trains (front-wheel drive with transversely mounted engines)
- Alternative Combustion Technologies (diesel, stratified change).

Most of these technologies are not new; they have been on the road for many years. Nevertheless, they are currently being emphasized in new vehicle configurations to increase fuel efficiency. Analyses by EPA and DOE have indicated that these technologies exhibit different shortfall behavior for two primary reasons. First, some of them are less sensitive to departures from the travel characteristics and travel environment of the EPA test procedure. Second, some of these technologies react adversely to the EPA test procedure compared to conventional technologies. An example of this is the increased rolling resistance for front-wheel drive cars in dynamometer tests due to the added weight (of the engine) over the drive wheels.

A review of the average shortfall (Δ mpg and on-road mpg/EPA mpg) for a variety of technology categories indicated that there are no consistent trends for vehicles disaggregated by size class, engine size (CID), and number of cylinders. Therefore, engineering considerations suggest the following classification system, which was selected to evaluate shortfall for all technologies.

Fuel System	Fuel injected gasoline Carburetted gasoline Diesel
Transmission	Automatic Manual
Drive Wheel	Front Rear

Traditional technologies are defined to include two groups: 1) carburetted, automatic, rear-wheel drive and 2) carburetted manual rear-wheel drive. Approximately 90 percent of the data collected for this study is related to these traditional technologies. The remaining ten percent is split among the following permutations of the alternative technologies:

- Fuel injected automatic front-wheel drive
- Fuel injected automatic rear-wheel drive
- Diesel automatic front-wheel drive
- Diesel automatic rear-wheel drive
- Carburetted automatic front-wheel drive
- Carburetted manual front-wheel drive

- Fuel injected manual front-wheel drive
- Fuel injected manual rear-wheel drive
- Diesel manual front-wheel drive
- Diesel manual rear-wheel drive

Unfortunately, the data and manufacturer representation required to produce industry average adjustment factors for each of these categories are not available. Therefore, this analysis will seek to determine whether there are significant differences in the shortfall behavior of these categories and if they can be combined in order to develop a common adjustment factor.

5.2.2 Shortfall Metrics

The analysis is faced at the outset with the issue of how to measure on-road shortfall and its dependence on other parameters. The questions revolve primarily around two matters:

- Whether to quantify shortfall as an absolute measure (i.e., an average change in fuel economy or fuel consumption compared to the EPA test) or as a relative measure (i.e., an average mpg- or gpm-ratio)
- In what manner to examine the functional dependence of the chosen measure on EPA fuel economy levels.

Resolving these issues and then choosing an appropriate analysis methodology requires considering both the engineering basis for shortfall and the real-world use and limitations of the shortfall relationships. The methodology chosen here is to measure shortfall as a gpm-ratio which is considered to be a function of the EPA composite fuel economy. As the analysis will show, shortfall is then well represented by linear functions:

$$\text{GPM-ratio} = a + b \cdot \text{EPA}_{\text{composite}}$$

These functions also will be approximately linear in other chosen spaces. The intent of this choice is to follow general engineering insight and to avoid methods which can produce divergent results when used for the purposes of labeling new vehicle fuel economy.

Fuel Economy Ratios

A pragmatic analysis goal is to develop simple expressions for on-road adjustment factors in light of the limitations in the current on-road data base and the incomplete engineering understanding of how the individual factors influencing shortfall interact.

The most basic issue is to determine the appropriate measure of shortfall. For the purposes of fuel economy labeling, the measure of shortfall has most often been considered a correction factor, a multiplicative constant. This choice recognizes previous work which showed that the difference between on-road and EPA fuel economy increases with the fuel economy level of the vehicle. A constant factor (either an mpg-ratio or a gpm-ratio) measures average shortfall as a percentage of the EPA composite fuel economy and, therefore, incorporates the increasing difference with increases in fuel economy levels. As the two-mode analysis of Section 6 shows, the multiplicative constant adjustment factor is indeed an effective method for correcting dynamometer values to on-road fuel economy. Fuel economy ratios therefore are more appropriate choices for a real-world labeling than the absolute measures of changes in fuel economy (Δmpg) or fuel consumption (Δgpm).

Most previous work in fuel economy shortfall has developed empirical relationships in gpm-space. The meaning and motivation for this choice is that fuel economy values (mpg) are inherently derived quantities. While in common use and the only meaningful form in which fuel efficiency information can be presented to consumers, fuel economy values are a non-linear transformation (reciprocal) of the physical quantity they measure -- fuel consumption. This engineering consideration has been influential in EEA's decision to measure shortfall as a gpm-ratio.

All effective work in simulation of vehicle efficiency has been built upon the relationships which govern fuel consumption rates: work performed for mass acceleration and overcoming aerodynamic forces, frictional losses, pumping losses, and others. In a study for DOE,[1/] EEA developed a simplified regression model which predicted fuel consumption rates (and fuel economy) from vehicle design specifications for use in estimating EPA composite ratings of the 1985 light-duty truck fleet. This model provides insight into the appropriate forms of shortfall functions.

The regression model specified dynamometer fuel consumption rates (FC) according to the equation:

$$FC_{EPA} = \frac{A \cdot ETW + B \cdot DYNO}{N_e N_t} + g$$

where

ETW = Equivalent test weight

DYNO = Dynamometer horsepower setting

N_e = Engine efficiency

N_t = Drive train efficiency

g = Energy consumption unproductive of motion (e.g., warm up and idle).

This form follows directly from the dynamic equations describing energy consumed for producing motion. Section 2 of this report described the influences which cause on-road fuel consumption to increase compared to the EPA-test rates. These fall generally into two broad classes: 1) environmental influences which extend across all vehicle types and 2) simulation variances which may affect some vehicles more strongly than others. Examples of the first include owner maintenance practices, weather, and road conditions, while the second kind of influence includes differences in driving habits, travel patterns, average speed, and trip length compared to the dynamometer driving cycles.

As an a priori hypothesis, the on-road influences will produce both increases in the g term, unrelated to specifics of vehicle design, and also decreases in engine and drive train efficiencies N_e and N_t. These lead to the following theoretical model of shortfall:

$$FC_{\text{on-road}} = a \ FC_{\text{EPA}} + b$$

where $a > 1$ and $b \sim 0$ are expected. The results from previous work using gpm-space measures confirm the magnitudes of the shortfall parameters a and b. Following this general model, one then develops the functional relationship for shortfall which is used in this analysis:

$$\text{GPM-Ratio} = \frac{FC_{\text{on-Road}}}{FC_{\text{EPA}}} = a + b \cdot EPA_{\text{MPG}}$$

This form satisfies the pragmatic requirement of a shortfall measure which is relative, since it involves a fuel economy ratio and incorporates the dependence of shortfall on the fuel economy level of a vehicle.

Space Considerations

The model form introduced above will be used to develop adjustment factors for fuel economy labeling. As such, the final use of the analysis will be to predict on-road fuel economy (an mpg-space measure) from dynamometer test results. The analysis results will then be presented in a different space (or metric) than employed in their development.

An appropriate consideration is the effect that the mathematical transformation to mpg-space will have on the linear gpm-space relationship.

It is a pragmatic limitation of the analysis that the on-road adjustment factors will be applied to vehicles not represented in the data. These include both the low-mpg vehicles produced for specialty markets and not achieving wide market penetration and high-mpg cars which were not produced in large numbers during the model years for which data are available. The shortfall relationships therefore will be extrapolated to fuel economy levels not represented in the data. The functional form chosen for the analysis should not produce divergent results if it is to be appropriate in a real-world labeling system.

It is easily shown that the gpm-ratio equation, when transformed to MPG-space, is of the form:

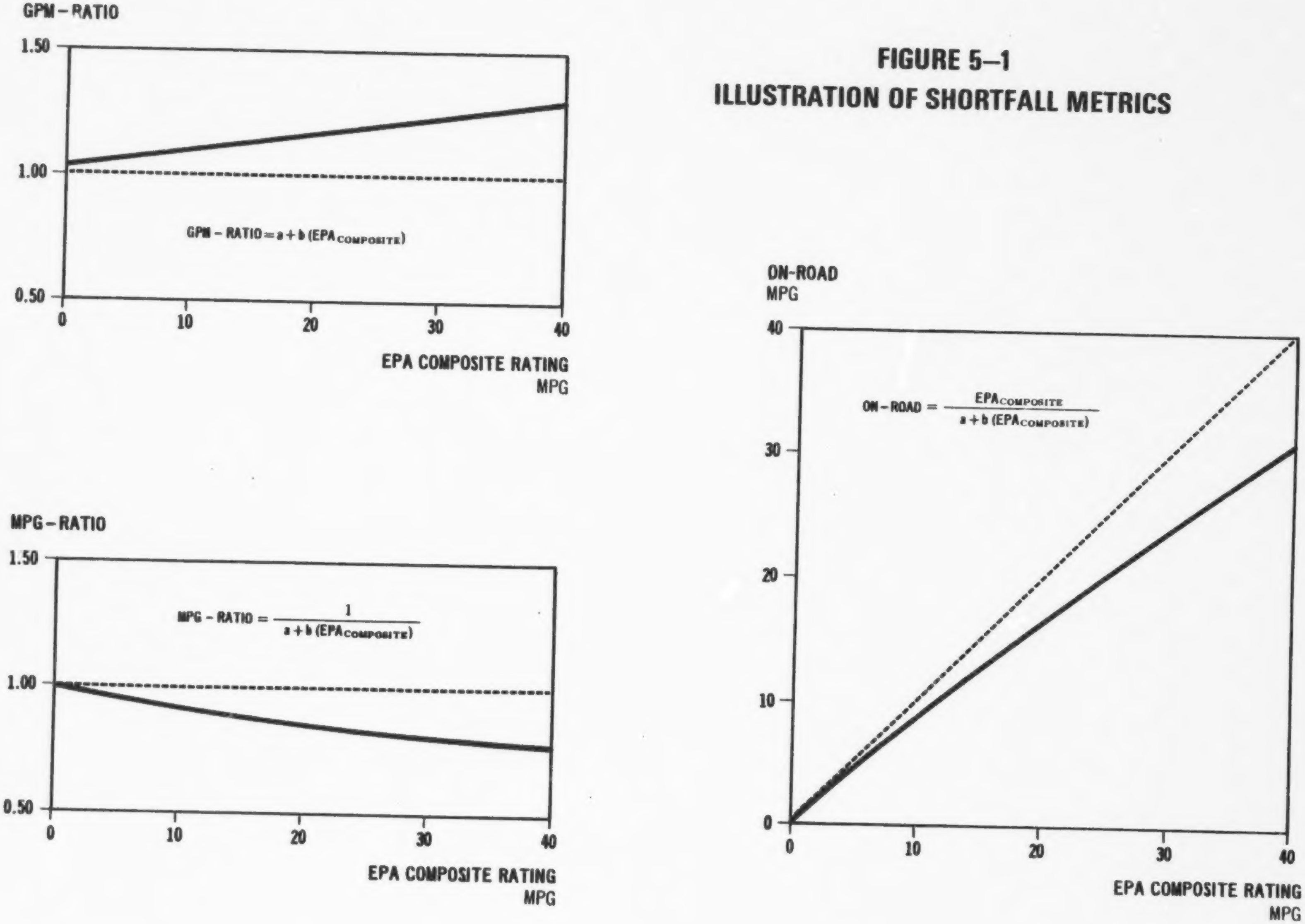
$$\text{On-Road MPG} = \frac{\text{EPA}_{\text{MPG}}}{a + b \cdot \text{EPA}_{\text{MPG}}}$$

Figure 5-1 shows the transformation of a space relationship, developed from the J.D. Power data base, to both an mpg-ratio relationship and a figure of on-road fuel economy. Over the range of the existing data, the relationships in other spaces also are approximately linear. When extrapolated to low fuel economy vehicles, the GPM-ratio factors will not produce large adjustments. In addition, the on-road values for high-mpg vehicles can not diverge toward zero fuel economy, but will instead show stabilizing percentage shortfall. This mathematical result is in keeping both with the need to avoid unreasonable adjustment factors and with limited evidence, presented in the analysis, that shortfall does not continue increasing on a percentage basis without bound.

5.3 ANALYSIS

The combined mode labeling system is the simplest of the 4 alternatives proposed for improving the accuracy of the fuel economy label values in the recent ANPRM.[2/] When adjustment factors are instituted for the technology categories having different shortfall characteristics, the

FIGURE 5–1
ILLUSTRATION OF SHORTFALL METRICS



composite label values will provide both relative rankings for comparison shopping and reliable estimates for what the public at large can expect from new cars. However, the single number system does not assist the public in choosing vehicles suited for their individual driving patterns, which as noted earlier is most often either predominantly urban or predominantly non-urban.

Shortfall for this system is measured relative to the EPA combined (55/45) fuel economy. It, therefore, includes the aggregate effect of differences in the public's driving patterns compared to the 55/45 city/highway mix, in addition to the influences of vehicle and road slip and dynamometer simulation variances. If use patterns vary with car size or fuel economy, the one-mode adjustment factors will discount the test results of low- and high-mpg vehicles for different reasons. The one-mode analysis also cannot distinguish how the individual influences may interact differently under city and highway conditions.

The system, therefore, is in some aspects less satisfactory than the two-mode system developed in Section 6 -- both from the perspective of the engineering analyst and from the consumer viewpoint. The previous work in shortfall has, however, collected a large body of data appropriate to the one-mode analysis. The data base covers all automotive technologies now on the road and so provides an excellent basis for defining the technology categories which should be treated separately in an adjustment factor system. The corresponding focus of the one-mode analysis is, therefore, toward the differing performance of the technologies.

5.3.1 Conventional Technologies

As discussed earlier in this section, the analysis for conventinal technologies will be conducted separately for automatic and manual transmission groups. The analysis is based on a total of 22,281 observations for rear-wheel drive carburetted cars. The distribution of the data by model year is presented below.

	Automatic	Manual
1975	41	73
1976	122	173
1977	3165	82
1978	5018	386
1979	8731	806
1980	3050	634
TOTAL	20127	2154

Manufacturer representation (percent distribution) among these transmission categories is as follows:

	AMC	CHRYSLER	FORD	GM	EUROPE	JAPAN
Automatic	3	11	51	34	0	1
Manual	1	3	64	16	*	16

It should be noted that Ford is disporportionately represented among the manufacturers to more than double their traditional market share. The inclusion of data from the Ford on-road surveys produces a manufacturer bias in the industry-wide analysis and will be addressed later in this section.

A summary of the composite shortfall relationships, using the gpm-ratio model discussed in the previous section, is shown in Table 5-1. Due to the test procedure change for manual transmission vehicles in 1979 the analysis was separated into two time categories, pre-1979 and post-1979 for both transmission categories. This allows a comparison of the relative differences in shortfall to determine whether the test procedure change influenced the performance of manual transmissions. Both a linear and a quadratic relation was tested for each of the time and

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* Substantially less than 1 percent.

TABLE 5-1

SUMMARY OF COMPOSITE SHORTFALL RELATIONSHIPS

(RWD-Carbureted Cars: Automatic and Manual Transmissions)

Model: $\text{GPM-Ratio} = a + b\ \text{EPA}_{\text{COMPOSITE}} + c\ (\text{EPA}_{\text{COMPOSITE}})^2$

	N	Mean Ratio	R^2	a	(SE)	b	(SE)	c	(SE)
Automatics									
Pre-1979	8346	1.215	0.021	1.022	(0.015)	0.00983	(0.00074)	(NS)	--
1979-1980	11781	1.114	0.039	0.887	(0.010)	0.01208	(0.00055)	(NS)	--
Manuals									
Pre-1979	724	1.142	0.071	0.863	(0.038)	0.010	(0.0014)	(NS)	--
1979-1980	1430	1.118	0.159	0.630	(0.030)	0.0189	(0.0011)	--	--
1979-1980	1430	1.118	0.029	(NS)	--	0.0679	(0.0011)	-0.000932	(0.00043)

(NS) Denotes coefficient not significant at the .05 level and has been omitted from regression.

(SE) Denotes standard error of estimate.

TABLE 5-1 (Continued)

SUMMARY OF COMPOSITE SHORTFALL RELATIONSHIPS
(RWD-Carbureted Cars: Automatic and Manual Transmissions)

Model: $\text{GPM-Ratio} = a + b\ \text{EPA}_{\text{COMPOSITE}} + c\ (\text{EPA}_{\text{COMPOSITE}})^2$

EPA Rating (MPG)	Automatics		Manuals		
	Pre-1979	1979-1980	Pre-1979	1979-1980 (1)	1979-1980 (2)
15	12.8	14.0	14.8	--	--
20	16.4	17.7	18.8	19.9	20.3
25	19.7	21.0	22.4	22.7	22.4
30	22.8	24.0	25.7	25.1	25.0
35	25.6	26.7	28.8	27.1	28.3
40	--	29.2	31.6	28.9	32.6

transmission categories. The results for the quadratic specification were not significant for any category except the 1979-1980 manual transmissions. That relation, however, appears to have inferior predictive power relative to the linear relation for the same data set.

The second page of Table 5-1 lists the predicted in-use mpg values for each of the relations on the previous page. Automatic transmissions show a decline in shortfall from the earlier to the later time period. Manual transmissions, however, show an increase in shortfall for compatible time periods between the two linear relations. The quadratic relation predicts a decline in shortfall for lower mpg values, an increase in the mid-range mpg values and a decline for higher mpg values. This apparent contradictory response to the change in the test procedure can be explained through a review of the data composition.

As noted earlier, Ford vehicles are disproportionately represented within the data set. The contributions of the three primary data sources to the 1979 and 1980 data set are listed below.

	Automatics	Manuals
DOE	2014	3
Ford	7502	1131
JD Power	2265	306

It is clear that the Ford data dominate the analysis in both transmission groups, since over 60 percent of the automatic data and almost 80 percent of the manual data is derived from the Ford on-road surveys. Table 5-2 provides a summary of the shortfall relations for both Ford and non-Ford data sources for 1979 and 1980 vehicles. The regressions indicate a significant difference in the Ford and non-Ford sources for manual transmissions, but not for the automatics. Figure 5-2 illustrates the relations for the aggregate pre-1979 data and the Ford and non-Ford sources for 1979 and 1980 for manual transmissions only. The non-Ford

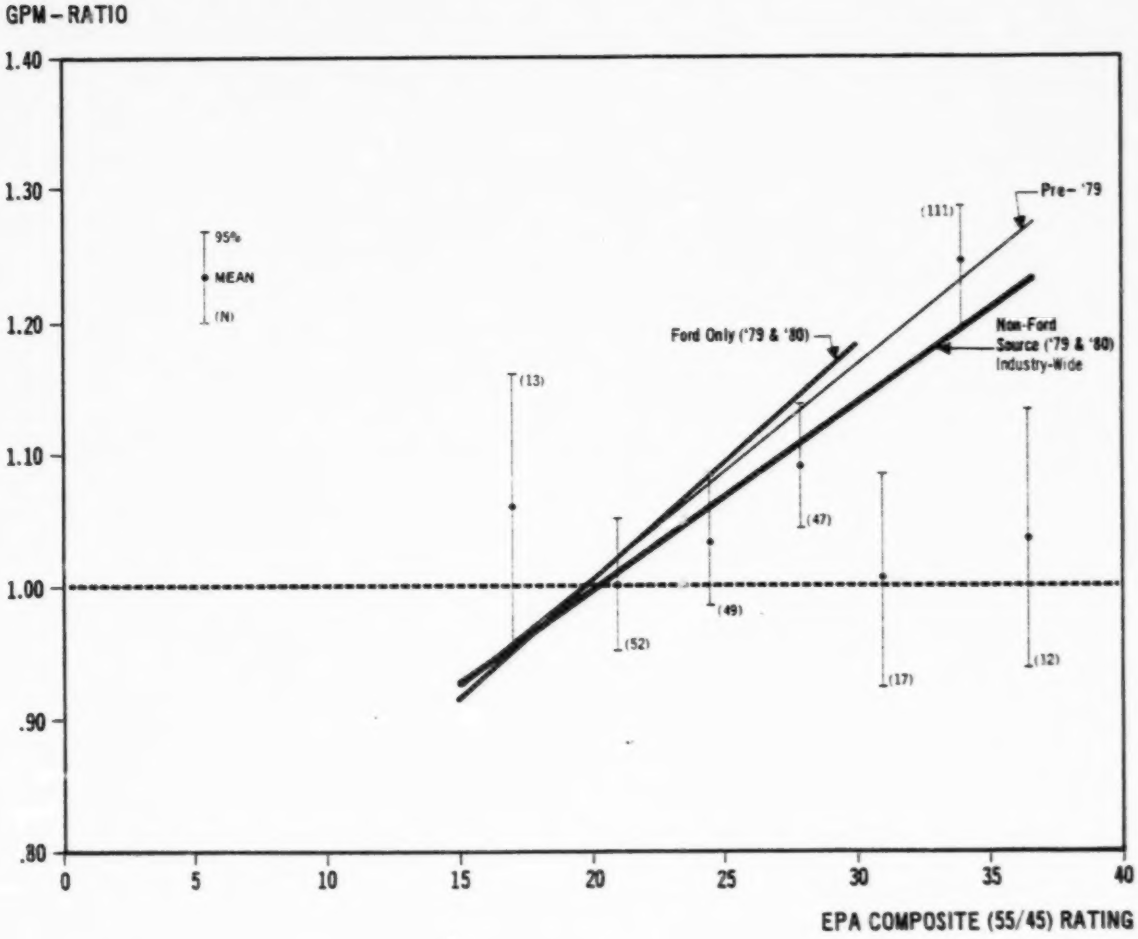
TABLE 5-2

REGRESSION ANALYSIS FOR 1979 AND 1980 RWD-CARBURETTED VEHICLES

Automatics	N	R^2	a	(SE)	b	(SE)	c	(SE)
Non-Ford Data								
Linear	4279	0.019	0.940	(0.021)	0.0099	(0.0011)	--	--
Quadratic	4279	0.028	0.315	(0.104)	0.073	(0.010)	0.00016	(0.00025)
Ford Data	7502	0.050	0.871	(0.012)	0.01261	(0.00064)	--	--
Aggregate	11781	0.039	0.887	(0.010)	0.01208	(0.00055)	--	--

Manuals	N	R^2	a	(SE)	b	(SE)
Non-Ford Data	299	0.138	0.714	(0.059)	0.0141	(0.0020)
Ford Data	1131	0.227	0.406	(0.039)	0.0283	(0.0016)
Aggregate	1430	0.159	0.630	(0.030)	0.0189	(0.0011)

FIGURE 5–2
RWD – CARBURETED MANUALS
1979–1980



NOTE: Data Shown for Non-Ford Sources Only ('79 & '80) relation, which contains a representative weighting of Ford vehicles in relation to their sales from the Power data, shows a decline in manual shortfall for the later years, a positive response to the test procedure change. The Ford-source data indicate an increase in shortfall relative to the pre-1979 relation. The Ford-source data are dominated by the performance of two models, the Pinto and the Bobcat. These models constitute approximately 75 percent of the Ford source and fall within the 24 to 28 mpg range. They, therefore, introduce strong model-specific effects when incorporated in the analysis of the manual vehicles. A brief discussion of the data used and the analysis results for separate transmission categories is presented below.

Manuals

The development of a shortfall relation that models industry average performance must not be biased by a unrepresentative sample of vehicles. Due to the narrow mpg range spanned by the two Ford vehicles and their disproportionate influence on the aggregate 1979 and 1980 relation, this data source was not used to develop the final relation. The relation based on the post-1978 DOE and J.D. Power data, containing a representative Ford sample, was selected to represent the performance of future manual transmissions. This relation still shows a response to the 1979 test procedure change, a reduction in shortfall.

Figure 5-2 illustrates the paucity of data beyond the EPA composite value of 35 mpg for the relation. Seen in the figure are indications of shortfall lower than the estimated 20 percent increase in consumption at 35 mpg level. Table 5-3 provides a detailed list of gpm ratios, standard errors, and EPA mpg values for all cars rated over 30 mpg EPA composite. The table indicates significantly higher shortfall for the 1979 Chevette relative to five Japanese models. (One Japanese model with high shortfall, the Subaru, has a four-wheel drivetrain). Whether future design trends will emulate the performance of these Japanese models or continue the

TABLE 5-3

RWD - CARBURETTED MANUALS ABOVE 30 MPG EPA COMPOSITE

(1979)

Model	Sample Size	EPA (mpg)	On-Road (mpg)	GPM-Ratio	(SE)
1979 Chevrolet Chevette	81/2*	34/33	27.9	1.241	(0.020)
1979 Datsun B-210	15	31	32.4	0.985	(0.043)
1979 Dodge Colt	11	34/37**	36.1	1.031	(0.037)
1979 Mazda GLC	11	34	33.0	1.028	(0.094)
1979 Mazda GLC (Wagon)	3	33	34.4	0.968	(0.063)
1979 Toyota Corolla (1.2L)	2	35	31.5	1.198	(0.323)
1979 Subaru (4WD)***	13	34	23.0	1.496	(0.047)

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* 49-State/California Certification

** Sedan/Hatchback

*** Tested as RWD during certification

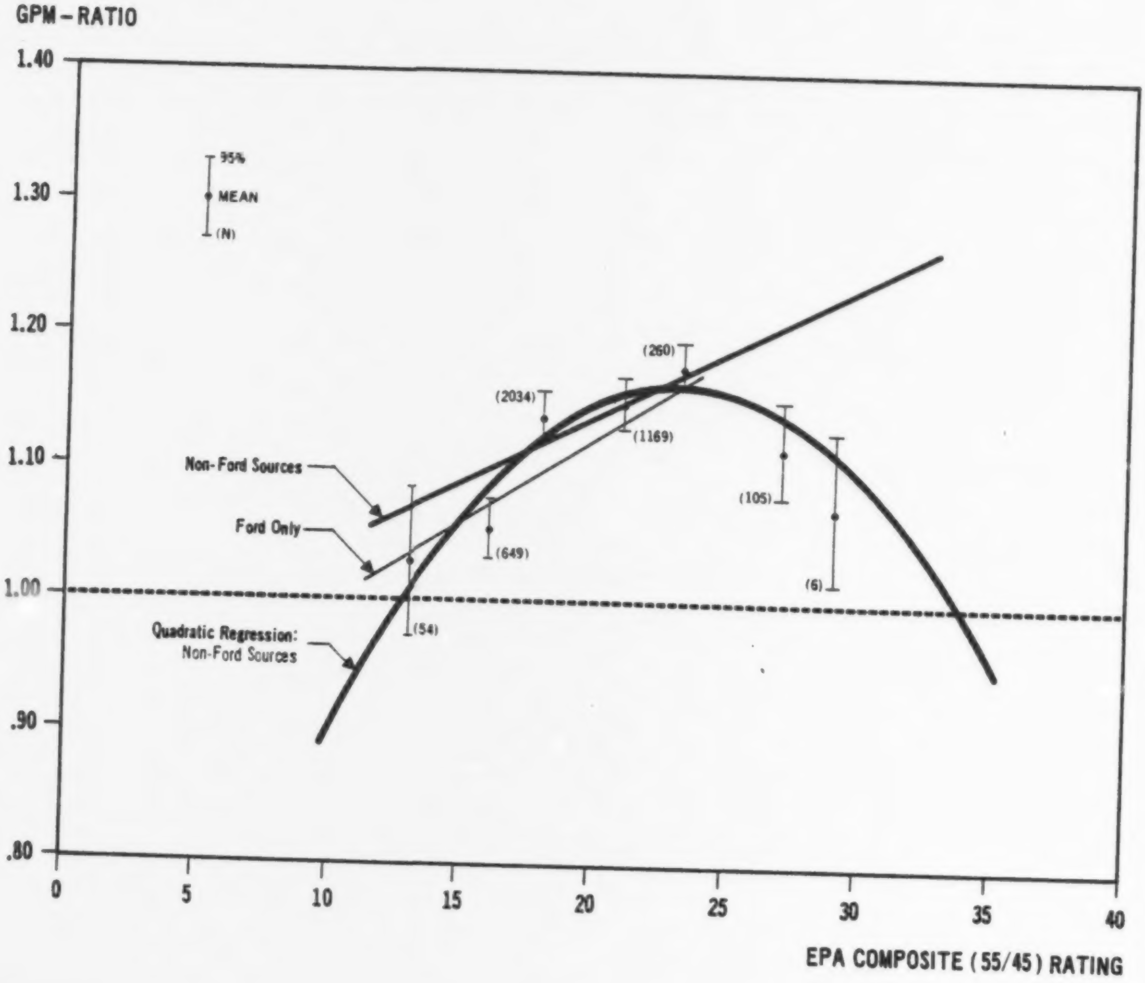
linear trend of increasing shortfall with increasing mpg is not clear. Until further data become available to document the performance of these higher mpg vehicles a cap of 20 percent will be placed on the shortfall of all higher fuel economy levels. At the lower end of the relation none of the mean values indicate on-road performance superior to the EPA test, i.e., less than 1.0 gpm ratio. Therefore, a lower bound of 1.0 will be placed on all mpg levels below 20 mpg.

Automatics

Table 5-2 also presented regressions for the performance of Ford source and non-Ford source data for automatic transmissions. Ford source dominance of the data, while not as strong as the manual transmissions, nevertheless constitutes almost 65 percent of the 1979 and 1980 data. This Ford source data, however, contain a representative distribution of Ford vehicles. The difference between Ford and non-Ford source data illustrated in Figure 5-3 is not particularly significant over the range of 15-25 mpg. The quadratic relation provides a different, if not interesting, fit to the data. It also points out the difficulty in projecting shortfall beyond a EPA composite estimate of 25 mpg. Two primary sets of vehicles are represented from 25 to 30 mpg, the Chevette and a collection of Japanese vehicles. Table 5-4 provides a detailed list of the GPM ratios for each of the models, their sample size, and related EPA value. The 1979 Chevette has a higher shortfall than the four Japanese models. The linear relation projects shortfall relatively close to the 1979 Chevette performance in the mpg region while the quadratic agrees better with the performance of the Japanese vehicles. Both relations appear to capture the performance of lower mpg vehicles reasonably well.

The outstanding question is similar to that for manual vehicles -- whether future vehicle designs emulate the performance of the Chevette or the Japanese vehicles. It is difficult to theorize why the sharp

FIGURE 5–3
RWD – CARBURATED AUTOMATICS
1979–1980



NOTE: Data Shown for Non-Ford Sources Only

TABLE 5-4

RWD - CARBURETTED AUTOMATICS ABOVE 25 MPG EPA COMPOSITE

(1979-1980)

Model	Sample Size	MEAN EPA (mpg)	MEAN On-Road (mpg)	MEAN GPM-Ratio	(SE)
1979 Chevrolet Chevette	72	27	23.9	1.157	(0.022)
1979 Datsun B-210	8	27	27.0	1.007	(0.029)
1979 Dodge Colt	3	29	27.0	1.081	(0.058)
1979 Toyota Corolla	15	26	26.0	1.028	(0.043)
1979 Mazda GLC (Wagon)	3	29	27.4	1.060	(0.014)
1980 Chevrolet Chevette	7	27	27.5	1.002	(0.061)
1980 Chevrolet Monza	3	27	22.8	1.191	(0.058)

curvature implied by the quadratic relation would be representative of future vehicle performance. By the same token, it is difficult to expect the shortfall of future vehicles to continue increasing at the rate implied by the linear relation. Therefore, it was decided to select the more conservative approach implied by the linear relation and to cap the shortfall at a 19 percent increase in consumption for 25 and higher mpg vehicles. Due to the minor differences between the Ford and non-Ford source data, the final relation is based on both data sets.

5.3.2 Alternative Technologies

As discussed in the beginning of this chapter, there are nine categories of alternative technologies and a correspondingly smaller data base. Tables 5-5 and 5-6 present a listing of the sample size and vehicles represented in each of the categories for gasoline and diesel vehicles respectively. Several of the gasoline categories have been divided into groups to account for significant differences in EPA mpg ratings. These groups also account for differences in vehicle design. For example, the fuel injected front-wheel drive automatic transmission category has Eldorados in one group and Audi Foxes and VW Scirocco's in another group. Aside from the obvious EPA mpg differences there are significant vehicle design differences between these groups. The Eldorado represents an older GM vehicle design with an early longitudinal front wheel drive technology in a 5500 lbs. vehicle. The Audi and VW vehicles represent light weight designs with transversely mounted engines. It is important to distinguish between current and outdated vehicle designs when developing adjustment factors to be applied to future vehicles. It is apparent after looking at the tables that the only category with adequate data for analysis is the carburetted manual front-wheel drive category, divided into two groups. The rest of the categories contain limited amounts of data and, in most cases, extremely poor model representation, two vehicles or less.

TABLE 5-5

ALTERNATE GASOLINE-ENGINE TECHNOLOGY GROUPS

Drive Wheels	Transmission	Fuel System	Model Name	Sample Size		
				pre-1979	1979-80	Total
RWD	Automatic	FI	BMW	1	1	2
			Cadillac Seville	12	9	21
			Lincolns	--	240	240
				13	250	263
RWD	Manual	FI	BMW	1	--	1
			Datsun 810	--	1	1
				1	1	2
FWD	Automatic	FI	Group 1 (EPA Composite <20)			
			Cadillac Eldorado	--	8	8
			Group 2 (EPA Composite >20)			
			Audi Fox	--	1	1
			Volkswagen Scirocco	5	1	5
				41	84	125
FWD	Manual	FI	Audi Fox	--	7	7
			Volkswagen Rabbit	36	76	112
			Volkswagen Scirocco	5	1	5
				41	84	125

TABLE 5-5 (Continued)

ALTERNATE GASOLINE-ENGINE TECHNOLOGY GROUPS

Drive Wheels	Transmission	Fuel System	Model Name	Sample Size		
				pre-1979	1979-80	Total
FWD	Automatic	Carb'd	Group 1 (EPA Composite <20)			
			Buick Riviera	3	5	8
			Cadillac Eldorado	6	--	6
			Oldsmobile Toronado	8	12	20
				17	17	34
			Group 2 (EPA Composite >20)			
			Honda Accord, Civic	18	4	22
			Subaru	1	1	2
			Chevrolet Citation	--	1	1
			Dodge Omni	18	36	54
			Plymouth Horizon	27	15	42
				64	70	134
FWD	Manual	Carb'd	Group 1 (EPA Composite <33)			
			Datsun F-10	6	--	6
			Honda Accord, Civic	25	35	60
			Volkswagen Rabbit	1	--	1
			Subaru	5	8	13

TABLE 5-5 (Continued)

ALTERNATE GASOLINE-ENGINE TECHNOLOGY GROUPS

Drive Wheels	Transmission	Fuel System	Model Name	Sample Size pre-1979	Sample Size 1979-80	Sample Size Total
FWD	Manual	Carb'd	(Group 1 Cont'd)			
			Ford Fiesta	--	325	325
			Dodge Omni	6	29	35
			Plymouth Horizon	6	74	80
			Datsun 310	--	20	20
			Chevrolet Citation	--	1	1
				49	492	541
FWD			Group 2 (EPA Composite >33)			
			Dodge Colt	--	1	1
			Honda Accord, Civic	57	--	57
			Subaru	3	5	8
			Ford Fiesta	38	--	38
				98	6	104

TABLE 5-6

DIESEL TECHNOLOGY GROUPS

Drive Wheels	Transmission	Model Name	Sample Size		
			pre-1979	1979-80	Total
RWD	Automatic	Cadillac Seville, Deville	-	11	11
		Olsmobile Cutlass, 88, 98	39	95	134
		Mercedes Benz	1	50	51
		Peugeot 504	2	15	17
			42	171	213
RWD	Manual	Peugeot 504	1	39	40
FWD	Automatic	Oldsmobile Toronado	--	2	2
FWD	Manual	Volkswagen Rabbit	17	55	72

Before determining whether regression analysis is viable for these categories, it is useful to review their mean GPM ratios which are presented in Table 5-7. The ratios for both earlier and later model years are presented. There are no clear cut trends in the shortfall implied by the ratios across model years or technology categories except that the smaller vehicles contained in the front-wheel drive categories appear to have extremely low shortfall levels. It should also be noted that all of these technologies have significantly lower levels of shortfall than the conventional technologies. This implies that, in the future, as these technologies increase their market penetration, the aggregate levels of shortfall for the new car fleet will decline relative to the performance of past new car fleets.

Table 5-8 provides a model by model list of the GPM ratios for carburetted manual front-wheel drive vehicles. Two things are clear from this table. First, there is a striking level of consistently low shortfall for almost all models with a sample size of greater than two. Second, the Fiesta, Honda Civic, and Accord all show significantly lower levels of shortfall for 1979 and 1980 relative to the pre-1979 vehicles. It is interesting to note that while the gpm ratio changed for the 1979-1980 Fiesta and the Accord, their on road mpg values hardly moved. This change in shortfall appears to be in response to the 1979 manual test procedure change. Therefore, the analysis will only consider 1979 and 1980 data for these vehicles.

The mean gpm value and 95 percent confidence bounds for each of the alternative technology categories are presented in Figure 5-4. Data for all models and all technologies are included except for the Fiesta and Accord. Also included for comparison are the regression relations derived for both transmission categories of conventional technologies. The 95 percent confidence bounds for these relations are also presented. Due to the large amount of data available for the rear-wheel drive carburetted automatic relation the confidence interval is essentially the width of the line.

TABLE 5-7

MEAN GPM RATIOS FOR ALTERNATE TECHNOLOGIES

Drive Wheels	Transmission	Fuel System	Group	Sample Size	GPM-Ratio	(SE)
RWD	Automatic	Diesel	pre-1979	42	1.094	0.026
			1979-1980	171	1.119	0.014
RWD	Manual	Diesel	pre-1979	1	1.121	---
			1979-1980	39	1.138	0.030
FWD	Automatic	Diesel	1979-1980	2	1.049	0.094
FWD	Manual	Diesel	pre-1979	17	1.001	0.021
			1979-1980	55	1.022	0.016
RWD	Automatic	Gas FI	pre-1979	13	1.141	0.047
			1979-1980	250	1.121	0.011
RWD	Manual	Gas FI	Both	2	1.860	---
FWD	Automatic	Carb'd	G1: pre-1979	17	0.941	0.046
			G1: 1979-1980	17	1.033	0.036
FWD	Automatic	Carb'd	G2: pre-1979	64	1.056	0.020
			G2: 1979-1980	70	1.016	0.014
FWD	Manual	Carb'd	G1: pre-1979	49	1.040	0.018
			G1: 1979-1980	492	0.977	0.005

TABLE 5-7 (Continued)

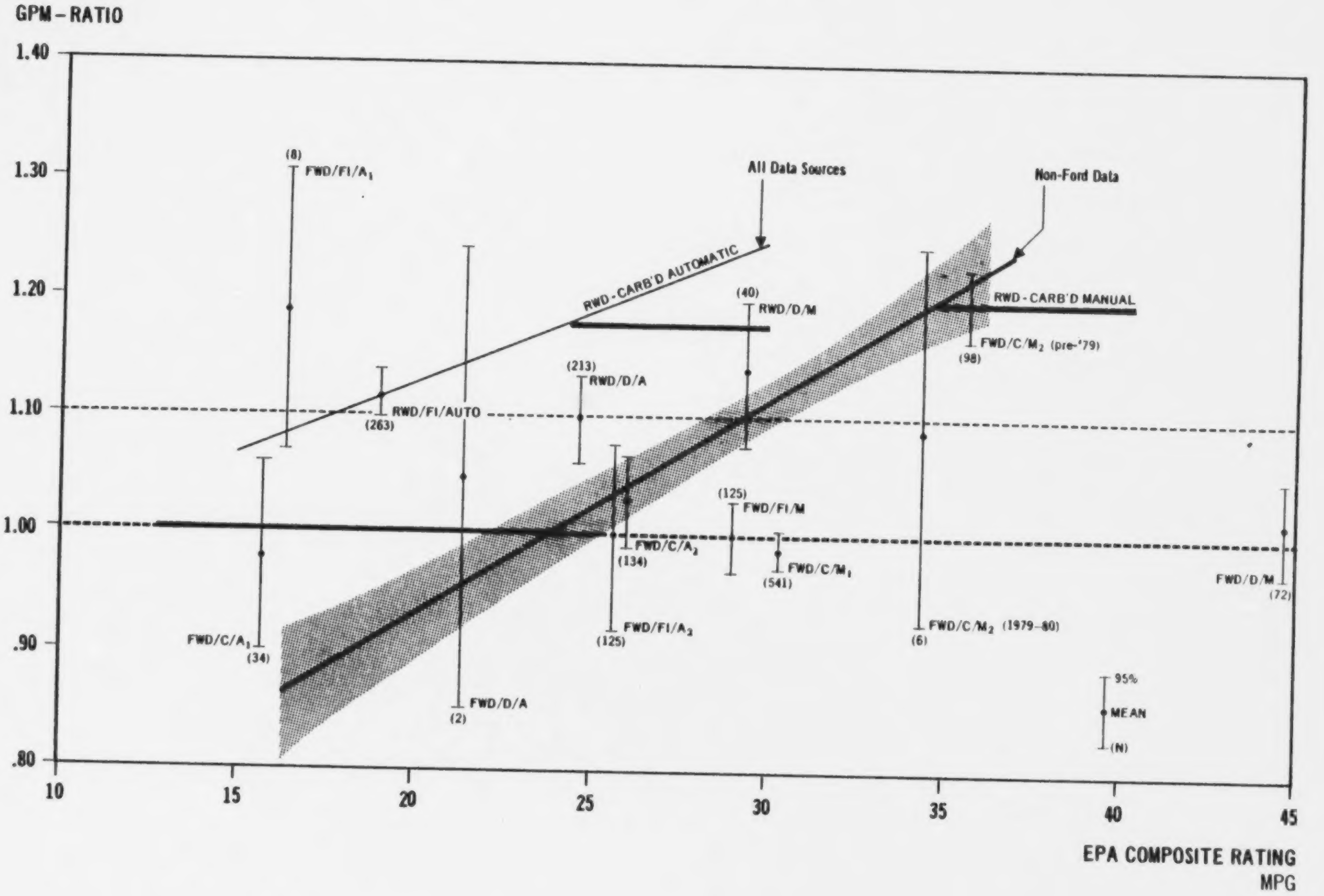
MEAN GPM RATIOS FOR ALTERNATE TECHNOLOGIES

Drive Wheels	Transmission	Fuel System	Group	Sample Size	GPM-Ratio	(SE)
FWD	Manual	Carb'd	G2: pre-1979	98	1.209	0.015
			G2: 1979-1980	6	1.089	0.088
FWD	Automatic	Gas FI	G1: 1979-1980	8	1.192	0.058
FWD	Automatic	Gas FI	G2: pre-1979	4	1.031	0.055
			G2: 1979-1980	7	0.972	0.034
FWD	Manual	Gas FI	pre-1979	41	1.006	0.030
			1979-1980	83	1.010	0.016

TABLE 5-8
AVERAGE SHORTFALL AND ON-ROAD FUEL ECONOMY FOR FWD/MANUAL/CARBURETTED CARS

Model	Period	Group	Sample Size	GPM-Ratio	(SE)	On-Road MPG	(SE)
Datsun F-10	pre-1979	1	6	1.082	0.070	32.51	
310	1979-1980	1	20	1.061	0.037	28.90	
Dodge Omni	pre-1979	1	6	0.953	0.021	30.44	
	1979-1980	1	29	0.989	0.018	30.33	
Plymouth Horizon	pre-1979	1	6	1.040	0.029	27.98	
	1979-1980	2	1	1.186	---	31.2	
Chevrolet Citation	1979-1980	1	1	1.362	---	21.8	
Honda CIVIC	pre-1979	1	15	1.073	0.030	29.83	
CIVIC (CVCC)	pre-1979	2	8	1.322	0.074	28.99	
	1979-1980	1	13	0.984	0.021	31.51	
Accord (CVCC)	pre-1979	2	49	1.211	0.021	30.12	
	1979-1980	1	15	0.929	0.027	31.21	
Ford Fiesta	pre-1979	2	38	1.197	0.0186	31.73	
	1979-1980	1	325	0.960	0.005	32.16	
Subaru (wagon)	pre-1979	1	5	1.002	0.062	30.94	
	1979-1980	1	8	1.033	0.059	30.32	
Sedan	pre-1979	2	3	1.015	0.048	36.46	
	1979-1980	2	5	1.070	0.105	31.70	
Volkswagen Rabbit	pre-1979	1	1	1.161	---	26.7	

FIGURE 5–4
CONVENTIONAL AND ALTERNATIVE TECHNOLOGIES



The large uncertainty associated with several of the alternative technology categories/groups are due to their very small sample size. The front-wheel drive diesel automatic category contains two vehicles; the front-wheel drive carbureted manual group two contains six vehicles. The front-wheel drive fuel injected automatics are divided into two groups. The first is made up entirely of Eldorados, using a relatively dated front-wheel drive design and has a shortfall higher than most conventional technologies. The second group, made up of Audi Foxes and VW Rabbits, using more advanced front-wheel drive designs, show essentially zero shortfall. Both carburetted automatic front-wheel drive groups also show very low levels of shortfall. The same relatively dated Eldorado designs show extremely low levels of shortfall compared to vehicles identical except for the difference between fuel injection and carburetion. Due to the low sample sizes the differences may be due entirely to sampling. The differences for these vehicles is not important because they are not expected to be available in the future.

Diesel technologies, in general, exhibit a range of shortfall. The automatic and manual rear wheel-drive diesels exhibit shortfall that is generally greater than the conventional manual transmission relation. The manual diesels, however, show a greater level of shortfall than the automatics contrary to the transmission influence in conventional technologies. The front-wheel drive diesels, if the two Toronado data points can be ignored, are represented solely by the Rabbits which have a very low level of shortfall. The cause for such a low level of shortfall for such a high mpg is unusual even among alternative technologies. The diesel Rabbit does, however, make use of three separate fuel efficient technologies -- diesel engines, manual transmissions, and front-wheel drive. The low level of shortfall cannot be ascribed to any one of these technologies, but to the interaction of all three. Unfortunately the data base contains no additional information on vehicles in this technology category that would allow a comparison for comparable levels of shortfall. Thus, the performance of this technology category is determined by the performance of one manufacturer, one model, and three fuel efficient technologies.

No additional trends are apparent for the remainder of the technologies. With the exception of the pre-1979 Accords and Fiestas and the older fuel injected Toronados, a strong case can be made that front-wheel drive provides the dominant technology influence to reduce shortfall. Of the three technology categories selected for analysis, drive wheel, transmission and fuel system, vehicles with front-wheel drive show consistently low levels of shortfall. Front-wheel drive is the only technology category that contains enough data and model representation to support regression analysis. It is tempting to ignore the contributions of the other technologies and pool all front-wheel drive vehicles to develop a relation that models their performance. A review of the data indicates that if the influence of the technologies within the front-wheel drive category had to be ranked, the only dominant influence is provided by diesels; the remainder of the fuel system and transmission categories do not appear to significantly influence the level of shortfall. A thorough examination of these influences is presented in Chapter 6.

A regression analysis of the shortfall for carburetted front wheel-drive automatic and manual transmissions is presented below:

Model: GPM Ratio = a + b EPA Composite

	N	Mean Ratio	R^2	a	(SE)	b	(SE)
Manual	583	.988	.006	.8145	(.0953)	.0058	(.0031)
Automatic	136	1.037	.001	.9491	(.2001)	.0033	(.0075)

The slope for the manual relation is significant at a six percent confidence interval. It indicates a slight increase in shortfall from the 25 to 40 mpg range from 0.96 to 1.04 gpm ratio. The slope for the automatic transmission is not statistically significant and indicates a constant shortfall of about 1.04 gpm ratio. If both categories are combined, it is quite likely that the slope would not be significant and that the mean shortfall would be zero or 1.0 gpm ratio. A thorough analysis of the contribution of individual technologies to shortfall is presented in Section 6.

Conclusions

Figure 5-4 shows that technology specifications will be essential to a credible on-road labeling system. The analysis demonstrates substantial shortfall differences between automatic- and manual-transmission conventional cars. The most appropriate one-mode adjustment factors for these technologies are the following:

- RWD-Carburetted Automatics:
  $$f_A = 0.887 + 0.01208 \cdot EPA_{COMPOSITE}$$
  with bounds $f_A \geq 1.00$ and $f_A = \leq 1.19$
- RWD-Carburetted Manuals:
  $$f_M = 0.714 + 0.0141 \cdot EPA_{COMPOSITE}$$
  with bounds $f_M \geq 1.00$ and $f_M \leq 1.20$

These relations are based on 1979 and 1980 data and, therefore, incorporate the effects of 1979 test procedure changes on manual shortfall.

Due to variations in vehicle design, model year representation, and data limitations, most of the alternative technology categories were judged to have insufficient data to warrant regression analysis. Those categories with sufficient data lacked an adequate spread in EPA mpg values to construct a meaningful regression. Nevertheless Table 5-9 contains summary statistics for each of the categories aggregated across model years. The information contained in this table is illustrated in Figure 5-4.

TABLE 5-9
SUMMARY STATISTICS FOR ALTERNATE TECHNOLOGIES

Drive Wheels	Fuel System	Transmission	Group	Frequency	GPM-Ratio
RWD	Diesel	Automatic	-	213	1.112
RWD	Diesel	Manual	-	40	1.137
RWD	FI (G)	Automatic	-	263	1.122
RWD	FI (G)	Manual	-	2	0.789
FWD	Carb'd	Automatic	1	34	0.987
FWD	Carb'd	Automatic	2	117	1.024
FWD	Carb'd	Manual*	1	526	0.981
FWD	Carb'd	Manual	2	9	1.064
FWD	Diesel	Automatic	-	2	1.049
FWD	Diesel	Manual	-	72	1.015
FWD	FI (G)	Automatic	1	8	1.192
FWD	FI (G)	Automatic	2	11	0.994
FWD	FI (G)	Manual	-	124	1.009

---

* The pre-1979 Honda's and Fiestas have been deleted due to their response to the 1979 test procedure change.

With the exception of the Eldorados, all front wheel drive technologies have extremely low levels of shortfall. Some of the individual category/groups have GPM ratios that indicate higher in-use than EPA fuel economy. Care should be taken in the extrapolation of the performance of these categories to future vehicles. For example, the manual diesel front-wheel drive category has essentially zero shortfall. This category, however, contains information on the performance of one vehicle, the diesel Rabbit. Given the background in performance (shortfall) variation between manufacturers for comparable technologies, it is not clear that the shortfall measured for one model for one manufacturer should be applied to the designs of all manufacturers in the future, unless this performance can be substantiated by additional data.

The available data do not justify the aggregation of the remaining technology categories, rear-wheel drive, fuel injected, or diesel vehicles. These categories include subsets of limited types of models which are not directly comparable in size, weight, or EPA mpg level.

FOOTNOTES FOR SECTION 5

1/ Energy and Environmental Analysis, Inc., 1980, Technical Analysis of the Light Duty Truck Fuel Economy Standards for 1985 Model Year. Prepared for U.S. DOE, Contract No. DE-AC01-79PE-70032, Arlington, Virginia, EEA, May 9.

2/ U.S. Environmental Protection Agency. Advance Notice of Proposed Rulemaking. Revisions to Improve Economy Labeling and the CAFE Data Base, 40 CFR Part 600, Docket No. A-80-32.

6. TWO MODE ANALYSIS

6.1 INTRODUCTION

Section 5 established some fundamental characteristics of fuel economy shortfall which an on-road adjustment factor system should incorporate. It showed that:

- On a percentage basis, shortfall for conventional technologies increases with EPA rating.
- Shortfall for the groups of alternative technologies is substantially less than expected from trends in conventional automobiles.
- Among rear-wheel-drive (RWD), carbureted cars, the manual transmission vehicles have lower shortfall than automatics of equal EPA ratings.

The analysis developed separate on-road adjustment factors for the RWD - carbureted cars with automatic or manual transmissions. These factors are linear functions of the EPA composite rating, appropriate to a one-mode system of fuel economy labeling. But because these factors are based on composite fuel economy, they do not measure whether shortfall differs in city or highway driving.

The purpose of this section is to develop similar adjustment factor relationships for a two-mode system of labeling. As in the previous analysis, available on-road data bases do not provide much information on the alternative technologies -- fuel injection, diesel engines, and front-wheel drive (FWD). While these technologies will be very common in future model years, they have not achieved wide market penetration to date and are represented in the data by a limited range of models. An initial constraint of the two-mode system is that a complete analysis of adjustment factors can be performed only for the two transmission groups of RWD-carbureted cars. The concluding section summarizes the two-mode data on alternative technologies and develops constant adjustment factors at the level of accuracy currently possible.

The two-mode factors are multi-parameter functions of the urban driving fraction and the EPA ratings. When evaluated for a specific vehicle in city driving conditions, for example, the adjusted on-road fuel economy then estimates what a consumer can expect on average in city driving. In this context, average means that a representative sample of new car buyers, operating the (adjusted) labeled vehicle in the city, will achieve on average a fuel economy equal to the label value. In practice, an individual may achieve more or less, due to the influences of driver habits and local conditions. The analysis indicates, however, that approximately 60 percent of drivers will get within ± 2 mpg. The median, or most typical, consumer will achieve the label value.

To provide an overview of the two-mode analysis, this section first presents a comprehensive discussion of the data requirements, methodology for constant factors, and evaluation of the adjustment factor systems. These components are common to the present analysis and also to any future study which has available an expanded and updated data base. In particular, Section 6.2 critiques the current data base in light of recommendations developed for the EPA on procedures for establishing manufacturer-specific adjustment factors. Section 6.3 then presents a preliminary analysis of the two-mode factors. This section focuses on the constant-ratio adjustment factor system, as recommended to the EPA, to introduce the methodology of the regression analysis. It also discusses in detail the resulting estimates of city and highway shortfall and evaluates the effectiveness of this simple system in labeling vehicles. Finally, Section 6.3 examines the EPA-dependence of shortfall within selected groups of city and highway drivers as guidance for specification of the two-mode model.

Section 6.4 presents the results of the two-mode analysis, which is based on model year 1978 and 1979 data collected in the J. D. Power/DOE surveys. This source is unique among currently available data bases in providing the necessary estimate of urban driving percentage for each respondent while containing a representative sample of vehicles produced by the auto industry. This section evaluates the recommended two-mode system in terms of the accuracy in predicting on-road fuel economy of the Power samples and also in its effectiveness in labeling the vehicles.

Finally, Section 6.5 summarizes the two-mode adjustment factors for alternative technologies. These have been developed from limited data and may not adequately measure on-road performance for the purposes of fuel economy labeling. While the categorization of the technologies is necessarily *ad hoc* in this analysis, the data do permit the development of factors for four different model lines. The results indicate that common two-mode factors for all gasoline-engine front-wheel drive technologies may be appropriate until additional data become available.

6.2 DATA REQUIREMENTS

To permit the analysis of two-mode adjustment factors for on-road fuel economy, a survey data base must indicate the city/highway driving split of each response in addition to the usual data on EPA ratings and on-road fuel economy. Among the currently available data bases, only the J.D. Power/DOE Surveys satisfy this requirement while representing a cross-section of the industry. A much larger data base is available from on-road surveys conducted by the Ford Motor Co. However, the development of industry-wide adjustment factors cannot be based on data representing only Ford vehicles. In practical terms, then, the two-mode analysis must be based on the Power data. The purpose of this section is to review the Power data base in light of the requirements for the two-mode analysis and to assess any limitations.

In support of its expected rulemaking, the EPA has commissioned a study[1/] of procedures for manufacturer specific labeling of new vehicle fuel economy. As discussed in the report, a manufacturer's data base for on-road adjustment factors should satisfy several requirements to assure accuracy and representativeness. These include:

(1) Coverage of the vehicles or vehicle classes operated across the range of geographical and seasonal factors influencing fuel economy.

(2) Descriptions of the surveyed vehicles to identify the fuel economy label values derived from EPA City and Highway dynamometer tests.

(3) A measure of each vehicle's typical driving mode, as the percentage of urban driving or as another variable which permits estimating this quantity.

(4) Fuel purchase data for calculating the on-road fuel economy

(5) Adequate sample size to achieve the level of accuracy specified by the EPA.

If the on-road survey does not represent regional and climatological factors in proportions approximating national occurrence, then the data base can be stratified and reweighted to correspond with national patterns. With conditions on total sample size and on minimum response rate for each identified stratum, these requirements specify an ideal data base for developing accurate and representative adjustment factors.

The Power surveys were not conducted for an adjustment factor analysis and do not completely satisfy each of the requirements listed above. The following discussion examines each requirement in turn and details the related advantages and disadvantages of the Power data.

Requirement 1

The primary advantages of the Power surveys are:

(1) Manufacturers are represented in proportion to their share of new car sales.

(2) Respondents are distributed regionally in proportion to national buying patterns and are representative of the car-buying public.

These strengths mean that the data base is very appropriate to developing industry-wide adjustment factors applicable to consumers nationwide. It is possible that individual manufacturers may require different adjustment factors, as envisioned in the procedures for manufacturer-specific exceptions. The current analysis, however, is constructed to develop industry-wide factors and does not attempt to treat one manufacturer differently from others. Geographic differences in shortfall also exist because climate and road conditions vary regionally. However, considering these environmental elements is not essential or practical in a nationwide new car labeling system.

The related limitations of the Power data are:

(1) The model years surveyed (1978 and 1979) are not representative of the current and future new car fleets.

(2) Seasonal influences on fuel economy are not completely balanced in the Power data, particularly so for model year 1979 vehicles.

The first of these limitations will remain characteristic of future on-road surveys because the automotive market and new car technologies are changing rapidly. In the current data, it results in the under-representation of vehicles above 25 mpg EPA composite, and proportionately too much emphasis on lower mileage vehicles. It also means that the adjustment factors developed for the higher EPA ratings are inherently less precise that for the lower ratings less typical of future cars.

The second limitation results from the sampling techniques used in the Power surveys and the time of year the surveys were conducted. The surveys included owners who purchased new vehicles in specific months -- August 1978 for model year 1978 vehicles in the first survey, and October 1978 and June 1979 for the 1979 vehicles of the first and second surveys, respectively. The first survey respondents were contacted in the Spring 1979, and the smaller sample of June 1979 buyers in Fall 1979. As a result, the three samples were on the road for differing periods of time and were subject to differing seasonal influences, as shown in Table 6-1.

The fuel economies of the 1978 sample should be relatively free of seasonal bias since the period of operation spans seven to eight months and includes both summer and winter driving. On the other hand, the two 1979 samples clearly represent either winter or summer driving and individually are biased relative to the annual-average fuel economy.

For the two-mode analysis, the 1978 data set has been accepted as representing annual-average shortfall, and the two 1979 data sets have been combined to reduce seasonal bias. Preliminary studies using weighted regression analysis show the adjustment factors for 1979 to vary by approximately two to three percent (toward lower shortfall) as the June 1979 data is given increasing weight to compensate for its smaller sample size. Equal weighting of the two (summer/winter) data sets requires per-vehicle weights of approximately 4:1 for the June data, and places too much emphasis on the relatively small sample. The 1979 data sets therefore are aggregated without relative weighting and should introduce no more than a three percent bias toward greater shortfall. Unfortunately, this bias will tend to obscure reductions in shortfall caused by the 1979 test procedure changes.

Requirement 2

The Power survey data describe vehicles in terms of model name, number of engine cylinders, and transmission type (including number of speeds).

TABLE 6-1

SEASONAL DISTRIBUTION OF THE POWER DATA

(RWD-Carburetted Vehicles Only)

	Model Year (Survey)		
	1978 (First)	1979 (First)	1979 (Second)
Total Sample Size	1968	1947	524
Automatics	1649	1794	394
Manuals	319	153	129
Month of Purchase	August 1978	October 1978	June 1979
Time of Survey	Spring 1979	Spring 1979	Fall 1979
Period of Operation	6 - 9 Months	4 - 7 Months	4 - 5 Months
Seasonal Characteristics	Summer/Winter	Winter	Summer

Note: Sample sizes include vehicles eliminated from the regression analysis due to low odometer readings.

The engine displacement is not given, so that vehicles are not always identified at a level corresponding to entries in the Gas Mileage Guide. The problem is most important for the models offered with several different V-8 engines. In assigning EPA ratings to the Power data, EEA has assumed that the vehicles are equipped with base or standard engines of the given cylinder-count. Assigned ratings are therefore biased upward on average whenever the cylinder count is an ambigous engine description. However, the differences among optional V-8's are typically no more than 2 mpg and these vehicles are located at the lower EPA ratings. This indicates the bias toward greater shortfall is small and associated primarily with the vehicles least typical of future fleets. No estimate of the bias (or correction for it) is possible with the data provided in the Power survey.

Requirement 3

An important factor in selecting the Power data base for this analysis is that its respondents were asked about their type of driving. The type of driving is measured here as the percentage of typical weekly driving done on urban roadways. This information generally has not been available in the fleet data collected by the Department of Energy over the past several model years. The Power surveys also collected data on trip length and permit inferring trip frequency and intensity of vehicle use. Correlation of urban percentage with these variables may at a future date allow use of other on-road surveys, which have not collected urban percentage, in a manner consistent with the present study.

Requirement 4

The on-road fuel economy values of the Power data are owner estimates, not necessarily based on records of fuel purchases. Although owner estimates are not the preferred source of fuel economy data, no other multi-manufacturer on-road survey using accumulated purchase data was available for the two-mode analysis. Practical considerations therefore require accepting the Power data until better sources become available.

The Power surveys asked respondents about their practices for keeping fuel economy records. Only the respondents indicating they kept accurate records at all times or checked fuel economy at least occasionally have been used in this analysis, as shown in Table 6-2. This selection excludes individuals who had the lowest awareness of fuel economy or did not indicate their practices. Unfortunately, the record-keeping practices are not known for the June 1979 buyers. It is therefore necessary to accept these data without screening.

In general, the best record-keepers report shortfall which is identical with previous DOE analysis of fleet data (based on actual purchase records). This indicates that owner estimates from accurate record-keepers are equivalent to purchase record data. The categories of owners who check fuel economy indicate lower shortfall (by approximately seven percent) and are therefore optimistic regarding their on-road fuel economy. These individuals may tend to check fuel economy during highway trips and therefore report values which are not typical of their overall driving mode.

The use of owner estimates in the analysis means, then, that the resulting shortfall relationships measure owner perception. By accepting only respondents indicating awareness through their reported record-keeping practices, the analysis focuses on the sample of consumers concerned about fuel economy. This differs from an analysis using fuel purchase data, which would be more appropriate for the purposes of aggregate fuel consumption projections.

Requirement 5

The analysis of data requirements for manufacturer-specific adjustment factors indicates that on-road surveys should satisfy one of the two sample size requirements:

TABLE 6-2

SAMPLE SIZE OF POWER DATA BY RECORD-KEEPING PRACTICE

	Model Year Sample (Purchase Month)		
	1978 (August 1978)	1979 (October 1978)	1979 (June 1979)
RWD-Carburetted Vehicles	1968	1947	527
AUTOMATICS ONLY			
1. Accurate Record Keepers	314	374	*
2. Frequent Checks	512	636	*
3. Occasional Checks	823	784	*
TOTAL	1649	1794	395
MANUALS ONLY			
1. Accurate Record Keepers	84	47	*
2. Frequent Checks	126	51	*
3. Occasional Checks	109	55	*
TOTAL	319	153	129

---

* Record-keeping behavior not known for June 1979 sample.

Note: Sample sizes include vehicles eliminated from the regression analysis due to low odometer readings.

(1) contain at least 156 responses in each of the subsets of vehicles operated only "in the city" or "on the highway"; or

(2) contain a total of 625 responses spanning all driving patterns.

These requirements assure that the uncertainty in the average adjusted label values will increase by no more that two percent, compared to approximately four percent uncertainty inherent in dynamometer testing.

The second criterion is applicable to the analysis methods used here. When data are accepted from three record-keeping groups (see Table 6-2), the Power data are fully adequate for determining adjustment factors of automatic transmission vehicles; the large sample of automatics also justifies separate analysis of the 1978 and 1979 data to look for effects of the 1979 test procedure changes. The total sample size of manual transmission vehicles (589) does not quite meet the specified criterion, however, and requires aggregating the 1978 and 1979 data. EEA judges the sample to be marginally adequate because the sample-size criteria were chosen conservatively. The 1978 and 1979 data bases individually are approximately one-half the necessary size. While the data are analyzed here by model year to examine effects of the 1979 test procedure changes, the results do not meet the specified two percent level of accuracy.

Summary of Limitations

When measured against the requirements recommended to the EPA, the primary shortcomings of the Power data are the following:

(1) The 1979 data is subject to seasonal bias, although this is reduced substantially through aggregating its winter and summer samples.

(2) Vehicles are not always identified at the level of the *Gas Mileage Guide*, so that some (primarily with V-8 engines) may be assigned EPA ratings one or two mpg too high.

(3) The fuel economy values are owner estimates and not calculated from fuel purchase records. The data have been screened for record-keeping practices to minimize the potential error, however.

(4) The sample size for manual transmission vehicles does not meet recommended targets and cannot support separate analyses by model year at the recommended two percent uncertainty level.

These limitations make the Power data base far from ideal. Yet, the Power surveys are the only available source covering the automotive industry and providing the requisite information on urban driving percentage.

6.3 PRELIMINARY ANALYSIS

The sample size criteria introduced above were developed by Falcon Research and Development in conjunction with two recommended procedures for quantifying the on-road adjustment factors.2/ While the constant-ratio factors envisioned in the recommendations do not fully describe the characteristics of on-road shortfall, the methodologies provide a starting point for developing a more appropriate model.

The first recommended approach isolates subsets of city and highway cars, i.e., vehicles driven only in urban areas or on the highways, and performs a straightforward shortfall analysis within each group.3/ This approach is used here to evaluate the EPA-dependence of city and highway shortfall; however, the methodology is limited by the availability of data. The recommended minimum sample size is 156 for each subset, which should include only the pure city and highway data of a survey. It therefore is difficult to achieve the desired level of accuracy with this approach.

The second recommended technique makes more economical use of survey data and is used here in a modified form to develop two-mode adjustment factors. The following discussion presents the technique as recommended to the EPA, before developing and evaluating alternate specifications for constant-ratio adjustment factors.

6.3.1 Recommended Procedure for Constant Adjustment Factors

Although shortfall increases with EPA rating for conventional vehicles, as a first approximation the adjustment factors may be assumed constants, f_c and f_h. The factors measure on average the increase in on-road fuel consumption relative to the EPA test results, and so are numbers greater than 1.* The adjusted label values are calculated as:

- Label City = EPA City/f_c (mpg)
- Label Highway = EPA Highway/f_h (mpg)

where the subscripts c and h indicate city and highway, respectively. The factors are developed simulataneously from regression analysis, using a model which measures on-road shortfall against a re-weighted EPA composite representing each respondents' reported split of city and highway driving.

For a respondent reporting an urban driving fraction u_i and overall on-road fuel consumption rate r_i (fuel economy R_i), the method postulates city and highway fuel consumption rates s_i and t_i, respectively, satisfying the relation

$$(1) \qquad r_i = u_i\, s_i + (1 - u_i)\, t_i$$

By definition of the adjustment factors f, and recognizing the inherent variability of real-world data, the city and highway consumption rates are estimated as

$$(2) \qquad \begin{aligned} s_i &= c_i\, f_c + \Delta\, s_i \\ t_i &= h_i\, f_h + \Delta\, t_i \end{aligned}$$

---

* This discussion is presented for a GPM-space analysis, although the recommendations were framed as mpg ratios. The nomenclature is adopted from those recommendations to facilitate comparisons.

where c_i and h_i are the vehicle's dynamometer fuel consumption rates over the urban- and highway-test driving cycles.

Substituting equations (2) into (1) and following the derivation in Reference 2, the following regression model for constant adjustment factors can be developed:

$$(3) \qquad \beta_i = f_h + (f_c - f_h)\,\gamma_i + e_i$$

$$\text{where} \quad \beta_i = \frac{r_i}{c_i\,u_i + h_i\,(1-u_i)}$$

$$\gamma_i = \frac{c_i\,u_i}{c_i\,u_i + h_i\,(1-u_i)}$$

As argued in the reference, the error term e_i should tend toward zero as a median value, and given a symmetric error distribution, also as a mean value. The distributions of the GPM-ratio β_i appear skewed in on-road data toward greater shortfall, resulting in median values less than the mean. Ordinary least squares regression will therefore produce adjustment factors slightly greater than a median regression analysis. The conservative nature of this result is, perhaps, advantageous to a real-world labeling system which must satisfy consumer expectations; the difference between median and mean is in any case small. For these reasons, and the associated simplification of the analysis, the present study has applied ordinary least-squares instead of the recommended median regression technique.

The terms of the regression model have interpretations which clarify their meaning. The quantity β measures shortfall as the GPM-ratio of on-road fuel economy to the dynamometer fuel economy estimated by re-weighting the EPA test results. The re-weighting develops an EPA composite fuel economy based on the respondents' reported urban fraction rather than the standard 55/45 split. This term therefore compares the fuel economy of city drivers ($u = 1.00$) against the EPA City rating, and that of highway drivers ($u = 0.00$) against the highway rating.

Equation (3) estimates the GPM-ratio β as a linear function of γ; in general, polynomials in γ may be required to fit the data. The quantity γ itself is composed of the urban fraction u weighted by the ratio of EPA city fuel consumption c to the re-weighted composite rate cu + h(1-u). For city drivers, γ takes on the value 1.00 and for highway drivers, the value 0.00. As shown in Table 6-3, the coefficients of equation (3) determine separate adjustment factors for city and highway driving.

In engineering terms, the quantity γ is the urban-cycle contribution cu to the re-weighted composite fuel consumption cu + h(1-u). It therefore is one measure of how important city driving conditions are to the overall driving pattern of a vehicle -- substantially the same information provided by the urban driving fraction itself. The more general model-building approach used in the present study is to examine the functional dependence of β on the urban fraction u and parameters which measure dynamometer fuel economy ratings.

The functional approach suggests, then, the alternate model for constant adjustment factors:

$$(4) \qquad \beta = f_h + (f_c - f_h)\, u$$

This has the advantage of a straightforward interpretation, since it measures the difference between city and highway shortfall directly as a function of how much city driving is done. In addition, the model is more flexible when shortfall also is treated as a function of EPA fuel economy level. The following section compares the models' predictions for constant adjustment factors and evaluates their effectiveness for two-mode labeling.

6.3.2 Evaluation of Constant Adjustment Factors

The 1978 and 1979 Power data have been analyzed using equations (3) and (4) for the two transmission groups of RWD-carbureted cars. The regres-

TABLE 6-3

SUMMARY OF REGRESSION MODEL FOR CONSTANT TWO-MODE FACTORS

Model

$$\beta = f_H + (f_c - f_H)\ \gamma$$

$$\beta = \frac{r}{c \cdot u + h(1-u)}$$

$$\gamma = \frac{c \cdot u}{c \cdot u + h(1-u)}$$

City Driving (u = 1.00)

$\cdot\ \beta = \frac{r}{c}$ and $\gamma = 1.00$

Therfore $\frac{r}{c} = f_H + (f_c - f_H)(1) = f_c$

and $r_c = cf_H$ $[R_c = C/f_H \text{ mpg}]$

Highway Driving (u = 0.00)

$\cdot\ \beta = \frac{r}{h}$ and $\gamma = 0.00$

Therfore $\frac{r}{h} = f_H + (f_c - f_H)(0) = f_H$

and $r_h = hf_H$ $[R_H = H/f_H \text{ mpg}]$

sion results, summarized in Tables 6-4 and 6-5, show substantial agreement between the models in terms of regression coefficients, R^2 values, and predicted adjustment factors. In both models, a quadratic term is required to fit adequately the data for 1979 automatic vehicles; in all other cases no quadratic effect is significant at the 0.05 level. When modified to include a quadratic term, the models become

$$\beta(\gamma) = a + b\gamma + c\gamma^2 \qquad (5)$$

$$\beta(u) = a + bu + cu^2$$

and the adjustment factors

$$f_c = a + b + c \qquad (6)$$

$$f_h = a$$

The low R^2 values for the regression models indicate that many other factors influence shortfall. These include, of course, car-to-car variability, differences across model lines, the influence of driver habits and maintenance practices, regional and climate differences, and also the dependence of shortfall on EPA fuel economy level. Among these sources, only the EPA dependence is essential to incorporate in a labeling system. Section 6.3.3 examines this element more closely.

Overall, there is a tendency for the $\beta(\gamma)$ model to predict larger adjustment factors by 1 or 2 percent, particularly for manual transmission vehicles, and to show slightly higher R^2 values. These effects are neither large nor important, compared to what the analysis shows regarding the characteristics and magnitudes of the city and highway shortfall.

The tabulated on-road adjustment factors show striking changes in manual-transmission shortfall which can be related to the 1979 test procedures changes. While the factors for automatic vehicles are approximately constant at 1.10 city, 1.36 highway, the change in allowed shift points

TABLE 6-4

SUMMARY OF CONSTANT ADJUSTMENT FACTOR ANALYSIS

(RWD - Carbureted Automatics)

MODEL YEAR 1978

Model	N	R^2	a	(SE)	b	(SE)
$\beta = a + b\gamma$	1711	.136	1.374	(.010)	-0.277	(.017)
$\beta = a + bu$	1711	.136	1.360	(.010)	-0.278	(.017)

MODEL YEAR 1979

Model	N	R^2	a	(SE)	b	(SE)	C	(SE)
$\beta = a + b\gamma + c\gamma^2$	2178	.122	1.350	(.011)	-0.395	(.057)	0.150	(.057)
$\beta = a + bu + cu^2$	2178	.124	1.350	(.011)	-0.493	(.057)	0.261	(.059)

CONSTANT ADJUSTMENT FACTORS

	$\beta(\gamma)$	$\beta(U)$
1978		
City	1.097 (.010)	1.082 (.010)
Highway	1.374 (.010)	1.360 (.010)
1979		
City	1.105 (.013)	1.118 (.015)
Highway	1.350 (.011)	1.350 (.011)

Note: Standard error of estimate cited in parentheses.

TABLE 6-5

SUMMARY OF CONSTANT ADJUSTMENT FACTOR ANALYSIS
(RWD - Carbureted Manuals)

MODEL YEARS 1978-1979

Model	N	R^2	a	(SE)	b	(SE)
$\beta = a + b\gamma$	589	.134	1.348	(.018)	-0.295	(.031)
$\beta = a + bu$	589	.129	1.331	(.017)	-0.296	(.032)

MODEL YEAR 1978

Model	N	R^2	a	(SE)	b	(SE)
$\beta = a + b\gamma$	313	.088	1.329	(.024)	-0.226	(.041)
$\beta = a + bu$	313	.086	1.316	(.023)	-0.227	(.042)

MODEL YEAR 1979

Model	N	R^2	a	(SE)	b	(SE)
$\beta = a + b\gamma$	276	.198	1.373	(.027)	-0.382	(.046)
$\beta = a + bu$	276	.192	1.351	(.025)	-0.385	(.048)

CONSTANT ADJUSTMENT FACTORS

	$\beta(\gamma)$	$\beta(u)$
1978-1979		
City	1.052 (.018)	1.034 (.020)
Highway	1.348 (.018)	1.331 (.017)
1978		
City	1.103 (.024)	1.090 (.026)
Highway	1.329 (.024)	1.316 (.028)
1979		
City	0.991 (.026)	0.966 (.029)
Highway	1.373 (.026)	1.350 (.024)

Note: Standard error of estimate cited in parentheses.

for manuals decreases city shortfall to effectively zero in 1979. The highway factors increase, however, by about 4 percent in 1979, which is approximately the magnitude of the expected seasonal bias (discussed in Section 6.2). As noted above, this analysis does not control for the EPA-dependence of shortfall, so that increases from 1978 to 1979 in the average EPA rating of the manual vehicles in the data base also will contribute to greater average shortfall. The constant adjustment factor analysis provides an initial estimate for the size of the city and highway factors.

Table 6-5 also indicates that the recommended sample size for this method of analysis is approximately correct. The aggregate 1978-1979 data for manual transmission vehicles does not quite meet the 625 target and produces adjustment factor estimates at the specified 2.0 percent limit of accuracy. The 1978 and 1979 data are, of course, not directly comparable as a result of test procedure changes; aggregation of the inhomogeneous data accordingly contributes to the variation and is responsible for a portion of the 2 percent uncertainty in the 1978-1979 results.

The results for the separate model-year analyses do not include variation associated with the test procedure changes. These utilize small samples, approximately 45 to 50 percent of the recommendations, and produce uncertainties in the adjustment factor estimates ranging from 2.4 to 2.9 percent. While the target limit of 2.0 percent is not reached in these analyses, little precision is lost with the much smaller data bases. This suggests that the recommendations are somewhat conservative, as intended in their derivation. They may therefore overstate survey requirements for manufacturer-specific adjustment factors, in which the manufacturer-to-manufacturer component of variation is absent. Further, model line-specific factors can be expected to have smaller sample requirements, since at this level the model-to-model variation also is eliminated. Section 6.5 derives constant adjustment factors for four model lines equipped with alternative technologies. As suggested by Table 6-22, a sample of 200 may be adequate to determine model-specific factors to within 2.0 to 2.5 percent. The EPA should consider the recommended sample sizes as guidelines for development of adequate on-road surveys; however, smaller surveys may be appropriate in many of the instances in which manufacturers apply for specific labeling.

Figures 6-1 and 6-2 illustrate the driving mode dependence exhibited by the 1979 data for automatics. In Figure 6-1, the 1979 regression line of the $\beta(\gamma)$ model has been plotted as a function of the independent variable γ. For comparison, the observed mean values of β within driving-mode subsets also are shown. The subsets are defined by the urban fraction u, indicated in parentheses above the 68 percent (one standard-error) confidence bands. Figure 6-2 presents the $\beta(u)$ regression line and shows the same mean values. Comparison of the figures demonstrates that the transformation from u to γ compresses the driving mode subsets (based on u) toward the city end of the spectrum. On Figure 6-2, the groups necessarily are evenly spaced. However, in other respects the two models represent the data well, with the $\beta(u)$ form providing a slightly better fit to the horizontal portion at the city end. Because the estimated adjustment factors are very similar, the two models also will be equally effective in labeling vehicles.

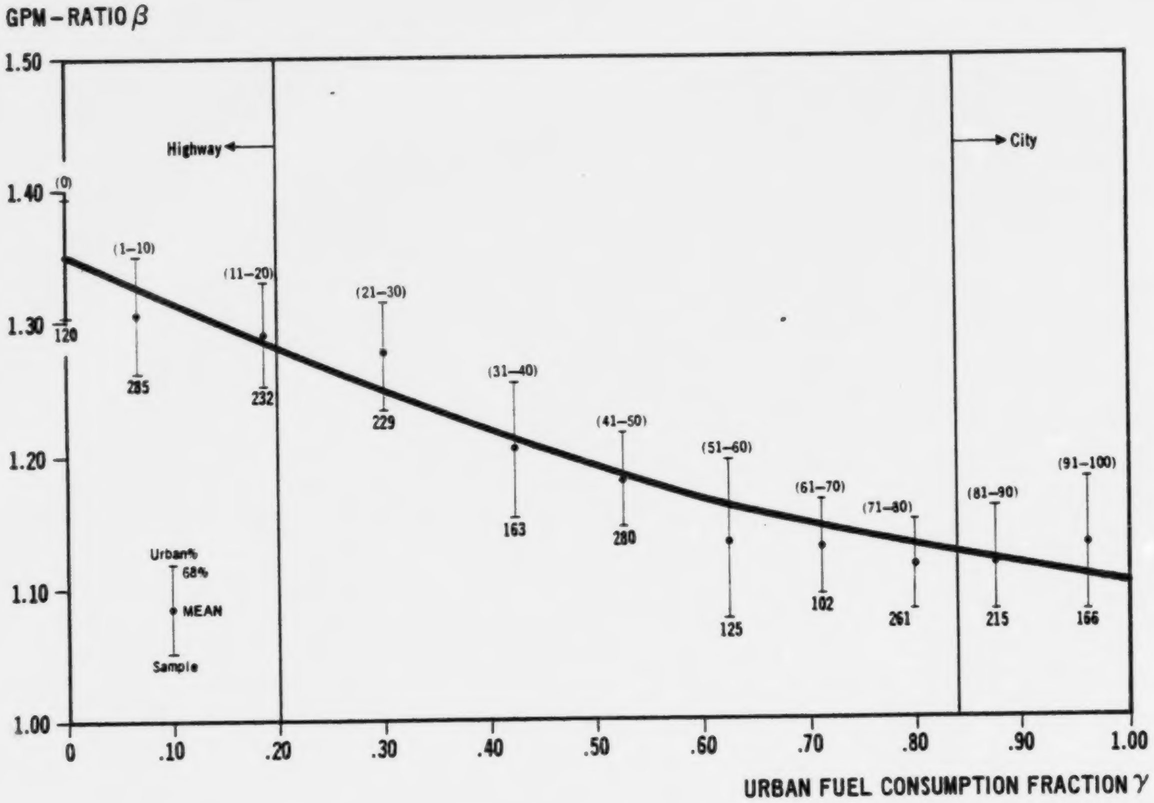
Evaluation for Labeling

The effectiveness of an adjustment factor labeling system is evaluated in two manners. First, the regression model provides a method of predicting on-road fuel economy. This evaluation uses the regression equation to predict a GPM-ratio β for each respondent. It then estimates an on-road fuel economy using the predicted β and the calculated (re-weighted) EPA composite rating. The predicted fuel economy is calculated as:

FIGURE 6–1

$\beta(\gamma)$ MODEL FOR CONSTANT FACTORS vs. MEAN GPM – RATIOS BY DRIVING MODE

1979 RWD – CARBURETED AUTOMATICS

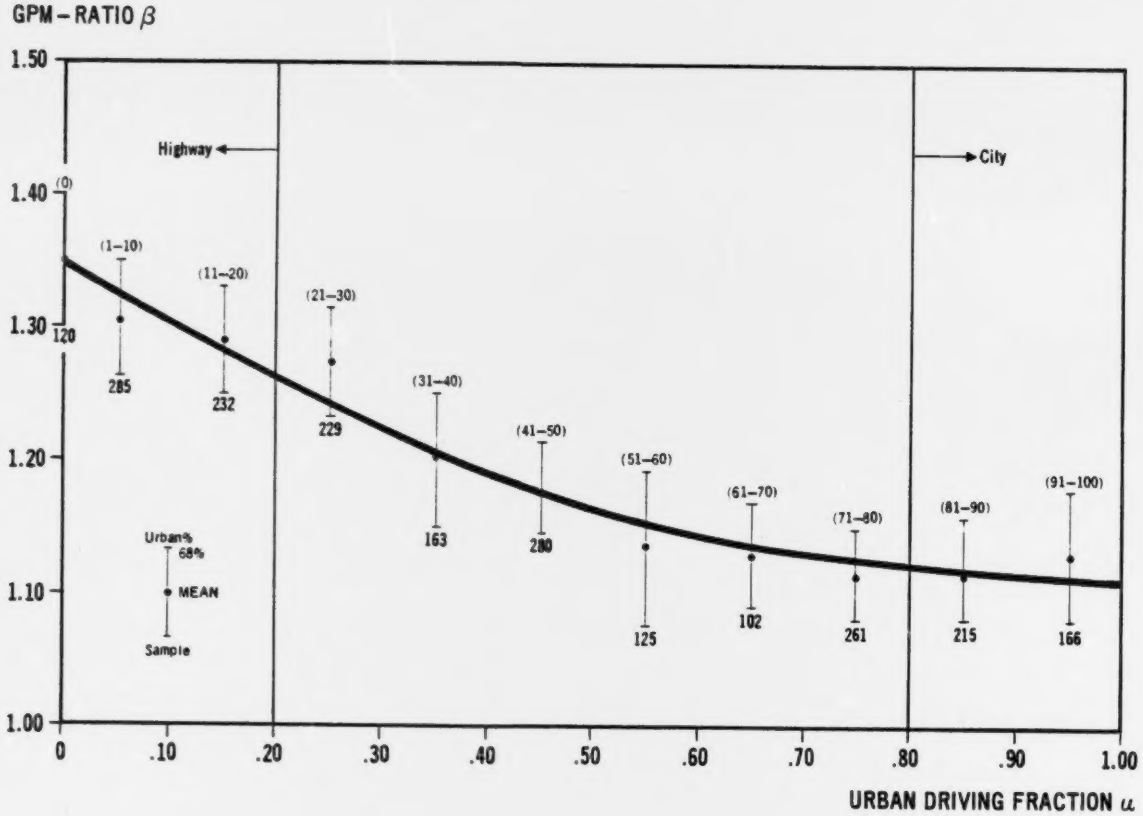


NOTE: 95 Percent Confidence Limits Represented by Width of Regression Line. Subsets for Mean Values Based on Urban Driving Percentage.

FIGURE 6–2

$\beta(u)$ MODEL FOR CONSTANT FACTORS vs. MEAN GPM–RATIOS BY DRIVING MODE

1979 RWD – CARBURETED AUTOMATICS



NOTE: 95 Percent Confidence Limits Represented by Width of Regression Line.

$$MPG^1 = \frac{\text{Rating}}{\beta}$$

$$\text{where} \quad \text{Rating} = \frac{1}{cu + h(1-u)} \qquad \text{(MPG)}$$

$$\text{and} \quad \beta = \beta(\gamma) \text{ or } \beta = \beta(u)$$

The distribution of the differences between reported and predicted fuel economy then provides a measure of the model's accuracy.

However, accuracy in predicting fuel economy is not the real-world measure of a labeling system's appropriateness. The second evaluation examines two issues:

- How many of the owners will achieve on-road fuel economies within the range of labeled on-road city and highway values?
- How widely separated are the labeled on-road city and highway values (mpg) for the vehicles of the sample?

In an effective labeling system, a large percentage of consumers should achieve on-road fuel economies within the city/highway range. If the numbers of consumers falling substantially below the adjusted city value (or above the highway value) are small, the adjustment factor system will present accurate and useful information. In addition, the system should provide a meaningful range of fuel economy; 2 or more mpg may be essential to achieving public acceptance. Finally, the system should avoid spurious results in which adjusted highway values are less than the city values. Vehicles which are poorly labeled by a two-mode system may be atypical -- because dynamometer tests produced an unusually small city/highway differential or because real-world performance is substantially different than for other vehicles.

Tables 6-6 through 6-10 evalute the constant adjustment factor systems found in Tables 6-4 and 6-5. Overall, the two models differ very little. In terms of accuracy in predicting fuel economy, the models achieve

TABLE 6-6

EVALUATION OF CONSTANT ADJUSTMENT FACTORS: ACCURACY IN FUEL ECONOMY PREDICTIONS

(percent of sample)

			Difference = Predicted MPG - Reported MPG					
		Sample Size	<-3	-2	-1	0	1	2	>3
AUTOMATICS									
1978	β(γ) Model	1711	23.2	11.5	13.7	13.0	12.2	9.9	10.5
	β(u) Model	1711	23.1	12.0	13.2	13.3	11.9	10.3	16.3
1979	β(γ) Model*	2178	20.1	12.5	14.7	14.8	13.5	9.0	15.5
	β(u) Model*	2178	20.3	12.4	14.8	15.2	12.9	9.0	15.5
MANUALS									
1978-1979	β(γ) Model	589	23.6	7.3	8.7	9.3	12.4	7.6	31.1
	β(u) Model	589	23.9	7.1	7.8	10.4	11.5	8.7	31.6
1978	β(γ) Model	313	29.4	7.7	11.5	12.5	8.3	7.0	23.6
	β(u) Model	313	29.7	6.7	11.8	12.8	8.6	7.0	23.3
1979	β(γ) Model	276	23.4	7.6	8.0	7.6	13.4	7.3	32.6
	β(u) Model	276	24.6	8.0	6.5	7.6	12.3	7.6	33.3

---

*Quadratic Models

Note: Figures may not add to 100 percent due to rounding.

TABLE 6-7

EVALUATION OF CONSTANT ADJUSTMENT FACTORS:
ON-ROAD FUEL ECONOMY COMPARED TO CITY/HIGHWAY LABEL VALUES

(percent of automatic transmission sample)

			Below City Value				Within Range	Above Highway Value			
AUTOMATICS ONLY		Sample Size	Total Below	3+ mpg	2 mpg	1 mpg	City/ Highway	1 mpg	2 mpg	3+ mpg	Total Above
All Drivers											
1978	β(γ)	1711	24.8	8.9	7.1	8.8	39.9	10.2	10.4	14.7	35.3
	β(u)	1711	30.2	12.3	9.2	8.7	36.1	9.4	10.5	13.3	33.2
1979	β(γ)	2177	20.6	7.0	5.7	7.9	41.8	12.2	10.2	15.2	37.6
	β(u)	2177	25.9	9.9	6.7	9.3	36.5	12.2	10.2	15.2	37.6
City Drivers (u > 80%)											
1978	β(γ)	356	35.3	16.0	10.7	8.7	38.5	5.3	10.7	10.1	26.1
	β(u)	356	41.5	21.3	12.1	8.1	32.6	5.9	10.4	9.6	25.9
1979	β(γ)	381	34.9	14.4	8.7	11.8	39.1	9.2	7.9	8.9	26.0
	β(u)	38±	42.3	20.5	7.9	13.9	31.8	9.2	7.9	8.9	26.0
Highway Drivers (u ≤ 20%)											
1978	β(γ)	449	13.8	4.2	4.5	5.1	37.9	14.9	12.9	20.5	48.3
	β(u)	449	19.2	6.5	5.6	7.1	35.0	14.0	12.9	18.9	45.8
1979	β(γ)	637	13.9	4.2	4.7	5.0	42.7	14.4	12.6	16.3	43.3
	β(u)	637	18.3	6.4	5.3	6.6	38.3	14.4	12.6	16.3	43.3

Note: Figures may not add to 100 percent due to rounding.

TABLE 6-8

EVALUATION OF CONSTANT ADJUSTMENT FACTORS: ON-ROAD FUEL ECONOMY COMPARED TO CITY/HIGHWAY LABEL VALUES

(percent of manual transmission sample)

			Below City Value			Within Range	Above Highway Value			
MANUALS	Sample Size	Total Below	3+ mpg	2 mpg	1 mpg	City/ Highway	1 mpg	2 mpg	3+ mpg	Total Above
All Drivers										
1978 $\beta(\gamma)$	589	27.8	15.1	6.8	5.9	36.5	6.5	6.6	22.6	35.7
1979 $\beta(u)$	589	29.9	18.2	5.9	5.8	37.4	6.8	4.9	21.1	32.8
1978 $\beta(\gamma)$	313	22.0	12.1	6.4	3.5	49.8	7.3	4.8	16.0	28.1
$\beta(u)$	313	27.2	16.0	4.5	6.7	45.0	8.3	3.5	16.0	27.8
1979 $\beta(\gamma)$	276	34.5	20.7	6.9	6.9	15.9	13.4	5.1	31.2	49.7
$\beta(u)$	276	41.6	27.5	6.9	7.2	19.2	6.5	4.3	28.6	39.4
City Drivers ($u > 80\%$)										
1978- $\beta(\gamma)$	87	37.9	16.1	16.1	5.7	39.1	4.6	4.6	13.8	23.0
1979 $\beta(u)$	87	42.4	24.1	8.0	10.3	34.5	5.7	4.6	12.6	22.9
1978 $\beta(\gamma)$	48	29.3	18.8	4.2	6.3	52.1	4.2	4.2	10.4	18.8
$\beta(u)$	48	35.4	20.8	4.2	10.4	45.8	6.3	2.1	10.4	18.8
1979 $\beta(\gamma)$	39	53.8	28.2	12.8	12.8	12.8	10.3	2.6	20.5	33.4
$\beta(u)$	39	61.5	41.0	12.8	7.7	10.3	7.7	2.6	17.9	28.2
Highway Drivers ($u \leq 20\%$)										
1978- $\beta(\gamma)$	143	18.9	10.5	2.8	5.6	37.1	9.8	5.6	28.7	44.1
1979 $\beta(u)$	143	19.6	11.2	5.6	2.8	41.3	7.7	5.6	25.9	39.2
1978 $\beta(\gamma)$	84	12.0	3.6	6.0	2.4	51.2	6.0	6.0	25.0	37.0
$\beta(u)$	84	15.5	8.3	1.2	6.0	47.6	6.0	6.0	25.0	37.0
1979 $\beta(\gamma)$	59	30.5	18.6	5.1	6.8	15.3	13.6	8.5	32.2	54.3
$\beta(u)$	59	35.6	23.7	6.8	5.1	18.6	11.9	6.8	28.8	47.5

Note: Figures may not add to 100 percent due to rounding.

TABLE 6-9

EVALUATION OF CONSTANT ADJUSTMENT FACTORS
SPREAD IN CITY/HIGHWAY LABEL VALUES

(percent of sample)

			Difference = Highway - City (mpg)									
		Sample Size	<0	0	1	2	3	4	5	6	7	8+
AUTOMATICS												
1978	$\beta(\gamma)$	1711	1.2	0.9	17.9	46.6	33.0	0.3	--	--	--	--
	$\beta(u)$	1711	0.8	4.2	24.7	64.9	5.0	0.3	--	--	--	--
1979	$\beta(\gamma)$*	2177	3.5	0.4	6.6	59.4	17.3	2.9	--	--	--	--
	$\beta(u)$*	2177	0.4	3.1	4.8	62.5	26.2	2.9	--	--	--	--
MANUALS												
1978-	$\beta(\gamma)$	589	0.2	3.4	13.8	31.6	23.9	11.5	7.5	8.2	--	--
1979	$\beta(u)$	589	2.0	2.7	12.7	33.5	21.7	10.0	7.8	2.6	7.0	--
1978	$\beta(\gamma)$	313	--	--	3.5	5.4	27.2	34.8	13.4	2.6	--	13.1
	$\beta(u)$	313	--	--	3.5	21.1	20.5	33.6	5.8	2.6	--	13.1
1979	$\beta(\gamma)$	276	12.7	33.0	20.3	14.1	13.0	6.9	--	--	--	--
	$\beta(u)$	276	13.8	42.0	12.3	25.0	6.9	--	--	--	--	--

---

*Quadratic Model

Note: Figures may not add to 100 percent due to rounding.

TABLE 6-10

SUMMARY OF POORLY LABELED CARS

Adjusted Highway < City	
Chevrolet Chevette	Manual
Chevrolet Monza	Manual
Datsun B-210	Manual
Datsun 510	Automatic and Manual
Dodge Colt	Manual
Mazda GLC	Manual
Plymouth Volare	Manual
Pontiac Sunbird	Manual
Toyota Corolla	Manual
Adjusted Highway = City	
AMC Concord	Manual
Buick Skylark	Manual
Chevrolet Chevette	Automatic
Datsun B-210	Automatic
Ford Fairmont	Manual
Mazda GLC Wagon	Manual
Mercury Zephyr	Manual
Pontiac Firebird	Automatic

results typical of more sophisticated models. As shown in Table 6-6, the factors predict on-road fuel economy to within ± 2 mpg for approximately 60 percent of the automatics, and 45 percent of the manuals. The addition of EPA-dependence to the models will not greatly improve this level of accuracy; the remaining variability is associated with factors specific to the drivers and vehicles. The manual fuel economies also are more variable as a result of the large influence of driver habits for these vehicles. Note that both models tend to underpredict fuel economy by approximately 0.5 mpg. This effect is inherent because of skewness in the GPM-ratio distributions.

Tables 6-7 and 6-8 compare the reported on-road fuel economies to the adjusted city and highway values for each vehicle. Across all types of driving, 40 percent of consumers will fall within the city/highway ranges. Owners of automatics have approximately a 1 in 4 chance of not achieving at least the city value, and only 10 percent will be three or more mpg below it. The manual transmission data are more variable, although these conclusions do not change substantially. Note that the 1979 data set for manuals is composed of separate summer and winter data and can be expected to show the larger deviations seen in Table 6-8. The constant adjustment factors are therefore very effective in estimating what consumers can expect.

In the city ($u > 80$ percent) and highway ($u \leq 20$ percent) subsets, larger fractions of motorists will fall below the appropriate label values. For example, approximately 40 percent of city drivers with automatics will be below the labeled city value, while 20 to 30 percent of highway drivers will fall below the highway estimate. The conservative nature of these results may aid in gaining consumer acceptance; the underprediction is in any case not severe and does not produce "lowball" estimates.

Table 6-9 completes the evaluation process by examining the distributions of differences between adjusted city and highway values. The automatics are typically labeled with a 2 mpg differential, while the higher fuel economies of manuals produce wider ranges -- normally 3 to 4 mpg. The label range for automatics will widen for future fleets as automatic fuel economy is improved. This trend also will serve to reduce the frequency of spurious label values.

Many of the poorly labeled cars are at the higher EPA ratings, as shown in Table 6-10. To some degree, the cases of equal adjusted city and highway values (and of highway values below the city) result from the precision of EPA values in the data base. These ratings are composed of the integer mpg values found in the Gas Mileage Guide and introduce round-off error which will not be present when adjustment factors are implemented for labeling. In addition, the higher-mpg cars will be assessed substantially different adjustment factors when EPA-dependence is introduced into the model. This also will lessen the frequency of spurious results, although vehicles with unusually small city/highway dynamometer differential will continue to be poorly labeled.

Summary

The evaluation of constant adjustment factors has shown that the two-mode system is capable of providing appropriate on-road fuel economy values which are meaningful to consumers both as estimates of city and highway fuel economy and as an expected range. The analysis results depend very little on the specification of the regression models examined since both apply essentially the same methodology: estimating shortfall as a function of the amount of city driving where shortfall is measured against a re-weighted EPA composite rating.

The primary advantage of the recommended $\beta(\gamma)$ model is that the variable γ incorporates information about each vehicle's dynomometer ratings, in addition to the urban driving fraction. It is therefore somewhat more appropriate for constant-factors than the simpler $\beta(u)$ model. The approach chosen for this analysis is to quantify separately the EPA-dependence of shortfall by augmenting the $\beta(u)$ model with parameters derived from the city and highway ratings. The modified model, developed in the following section, therefore utilizes the same information contained in the $\beta(\gamma)$ specification but has the added capability to measure shortfall as a direct function of EPA level.

6.3.3 Analyses of EPA-Dependence

The regression models for constant adjustment factors can be extended in several ways to incorporate the EPA-dependence of on-road shortfall. For example, if the correction factors are assumed to be linear functions of the EPA city and highway rating, C and H, respectively, the $\beta(\gamma)$ model can be modified as follows:

$$\beta = a_H + (a_c - a_H)\ \gamma + b_c \gamma C + b_H\ (1-\gamma)\ H$$

where

$$\beta = \frac{r}{cu + h\ (1-u)} \qquad [r = {}^1/\text{Road, mpg}]$$

$$\gamma = \frac{uc}{uc + (1-u)\ h} \qquad [c = {}^1/C\text{, gpm}]$$

$$1-\gamma = \frac{(1 - u)h}{uc + (1-u)\ h} \qquad [h = {}^1/H\text{, gpm}]$$

A comparable linear form also exists for the $\beta(u)$ model:

$$\beta = a_H + (a_c - a_H)\ u + b_c\ u\ C + b_H\ (1-u)\ H$$

Note that in these models the linear terms in C and H are weighted by either γ or u, so that the pure city ($\gamma, u = 1$) and highway ($\gamma, u = 0$) vehicles of the sample are represented by the adjustment factor expressions:

- City: $f_c = \frac{r}{c} = a_c + b_c\ C$

- Highway: $f_c = \frac{r}{h} = a_H + b_H H$

In the absence of a preliminary analysis of the EPA-dependence of adjustment factors, the appropriate form of the fuel $\beta(\gamma)$ or $\beta(u)$ regression model is not easily specified. The first of two analysis techniques recommended to the EPA uses the subsets of pure city and highway vehicles to determine the two-mode adjustment factors. Although the sample sizes are small for the pure subsets in the Power data, less strict criteria can be employed to select groups of vehicles operated primarily in the city or the highway for a preliminary analysis of the EPA-dependence. This approach provides guidance in specifying the final correction factor model and also gives an understanding of how the differences between city and highway shortfall would influence the effectiveness of resulting two-mode factors.

Table 6-11 defines the driving mode subset used in this analysis. The 1978 and 1979 data have been pooled to increase sample sizes in the subsets, although this obscures model year differences in shortfall for manual vehicles. The results for automatics are not affected by the aggregation.

Analysis

Table 6-12 summarizes the separate city and highway regressions performed for the carbureted vehicles with automatic transmissions. The accompanying Figures 6-3 and 6-4 illustrate the regression equations and the mean values of the GPM ratios. The figures also show the observed ratios within bins based on the EPA city or highway rating. Where sample sizes permit, the bins include only vehicles with the same EPA rating, although they extend across three mpg at the extremes of the samples.

The shortfall observed in each driving mode clearly increases with the EPA rating. As seen in Figure 6-3, the relationship for automatics

TABLE 6-11

DRIVING MODE SUBSETS FOR PRELIMINARY ANALYSIS
(1978-1979 RDW-Carbureted Vehicles)

City Subset

- Urban percentage u > 80 percent
- Sample sizes

	Automatics	Manuals
1978	356	48
1979	381	39
TOTAL	737	87

Highway Subset

- Urban percentage u $\leq$ 20 percent
- Sample sizes

	Automatics	Manuals
1978	449	84
1979	637	59
TOTAL	1,086	143

TABLE 6-12

REGRESSION ANALYSIS FOR DRIVING MODE SUBSETS

(RDW-Carbureted Automatics)

City

Model	N	R^2	a	(SE)	b	(SE)	q	(SE)
$\beta_c = a + bC$	737	0.0451	0.782	(0.053)	0.0181	(0.0031)	--	--
$\beta_c = a + bC + qC^2$	737	0.0489	0.417	(0.217)	0.059	(0.024)	-0.00112	(0.00064)

Note: Quadratic coefficient q is significant at the 0.10 level.

Highway

Model	N	R^2	a	(SE)	b	(SE)
$\beta_H = a + bH$	1086	0.0158	1.130	(0.055)	0.0097	(0.0023)

Legend: (SE) denotes standard error of estimate.

FIGURE 6–3
CITY DRIVING GROUP: RWD – CARBURETED AUTOMATICS
URBAN PERCENTAGE > 80%

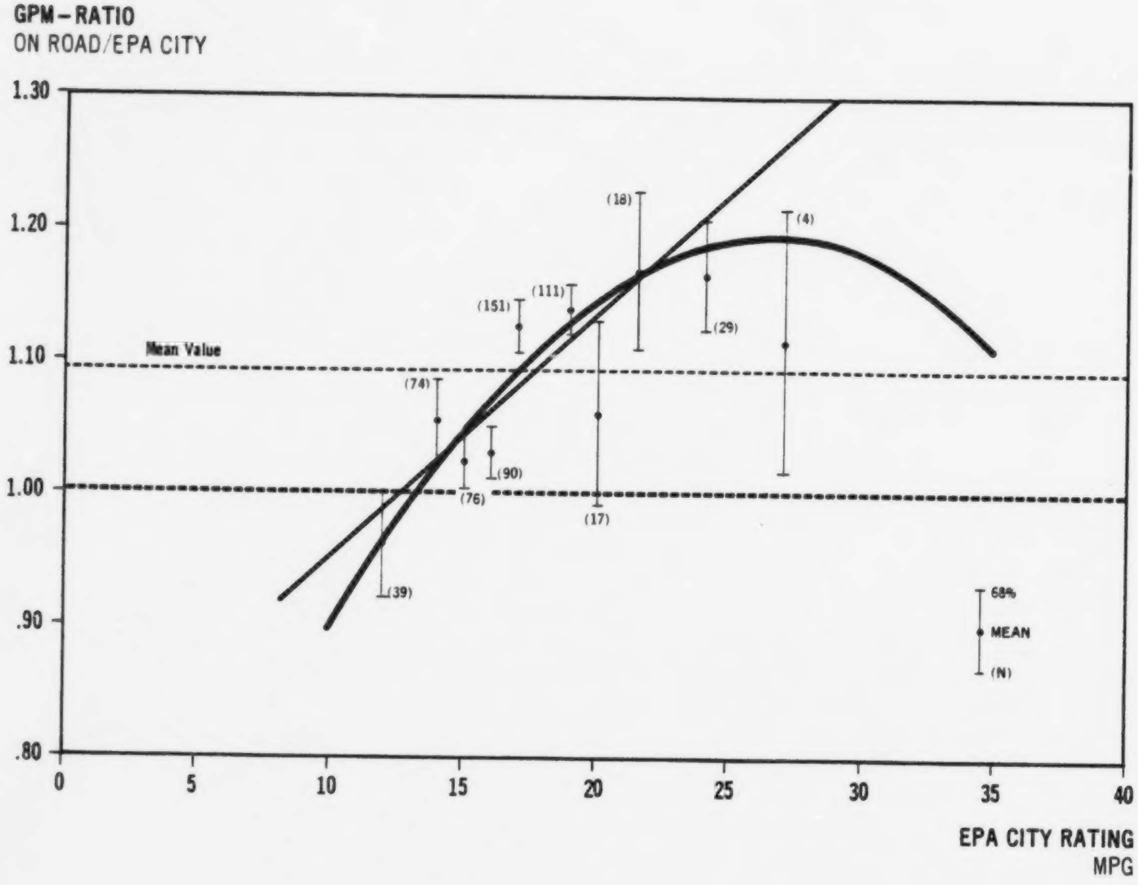
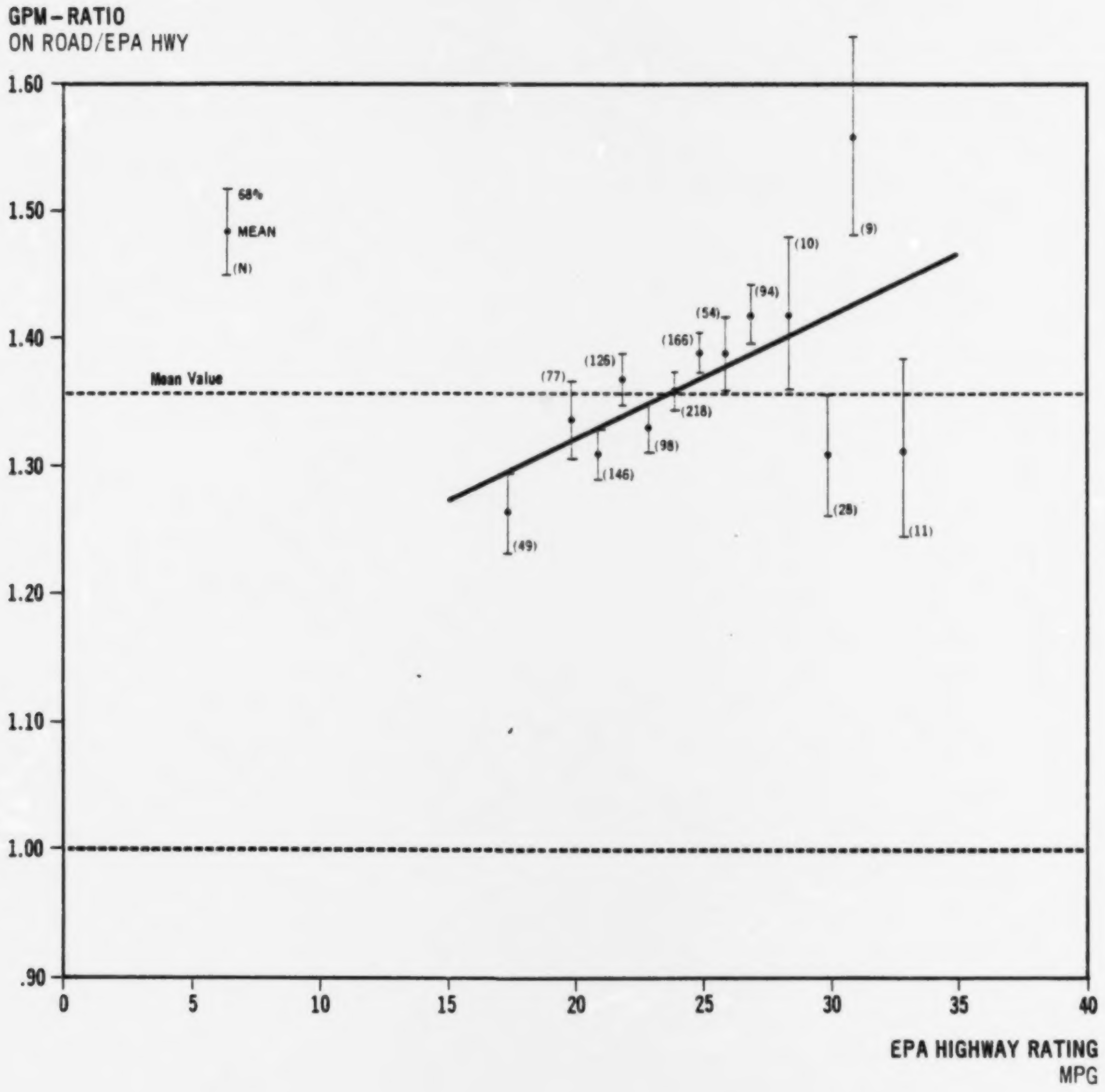


FIGURE 6–4

HIGHWAY DRIVING GROUP: RWD – CARBURETED AUTOMATICS

URBAN PERCENTAGE ≤ 20%



operated in the city is curvilinear and indicates that shortfall may stabilize (or perhaps decline) above 25 mpg city. Both linear and quadratic models fit the data well within the range of the sample, however. The highway group is represented very well by the linear function except for the vehicles above 29 mpg highway. Note that the confidence limits presented in the figures are one standard-deviation bounds; the groups at higher EPA ratings are generally not distinguishable from the linear representations.

The city and highway sample sizes for manuals are very small, but as shown in Table 6-13 and Figures 6-5 and 6-6, shortfall also is a function of the EPA city and highway values. There is no indication of non-linear trends in either the city or highway groups and so the linear specifications appear very appropriate.

These results indicate that the adjustment factors are approximately linear functions of the EPA city and higway ratings within the range of current data. However, the city factor for automotics may substantially overstate shortfall for the higher mpg cars if based on the linear relationship. The quadratic model produces a flattening of the shortfall line above 20 mpg but also demonstrates a strong curvature above 30 mpg. This is an artifact of the model and is not supported by data. All driving groups have very poor data representation for the fuel economy levels most typical of future cars and, in fact, include no automatics above 30 mpg city and only nine manuals rated above 40 mpg highway. As a result, the development of adjustment factors for the many high-mpg cars now being produced will necessarily extrapolate trends observed in the lower fuel economy ranges. The model specification must therefore, be tempered by the limitations of the data and the real-world application of the adjustment factor systems.

TABLE 6-13

REGRESSION ANALYSIS FOR DRIVING MODE SUBSETS

(RWD-Carbureted Manuals)

City

Model	N	R^2	a	(SE)	b	(SE)
$\beta_c = a + bC$	87	0.110	0.717	(0.100)	0.0134	(0.0041)

Highway

Model	N	R^2	a	(SE)	b	(SE)
$\beta_H = a + bH$	143	0.063	1.017	(0.111)	0.0097	(0.0031)

Legend: (SE) denotes standard error of estimate.

FIGURE 6–5

CITY DRIVING GROUP: RWD – CARBURETED MANUALS

URBAN PERCENTAGE > 80%

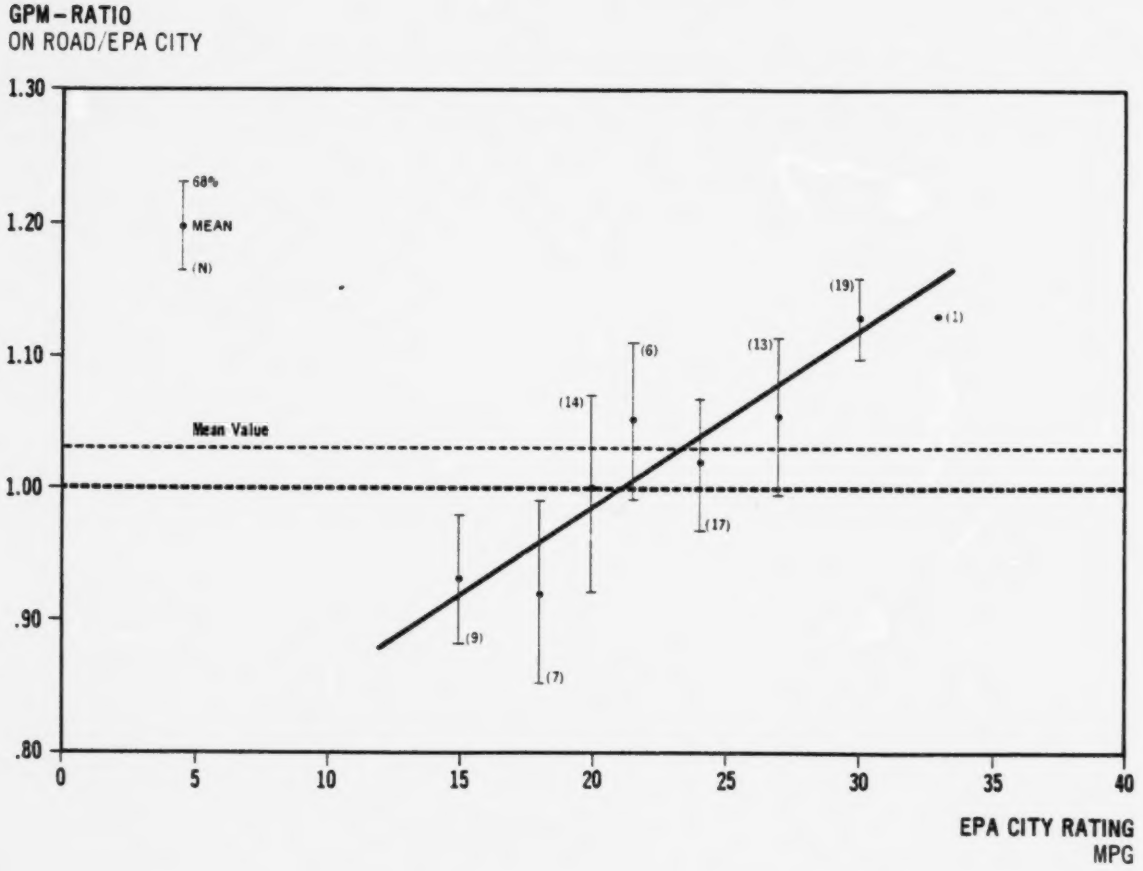
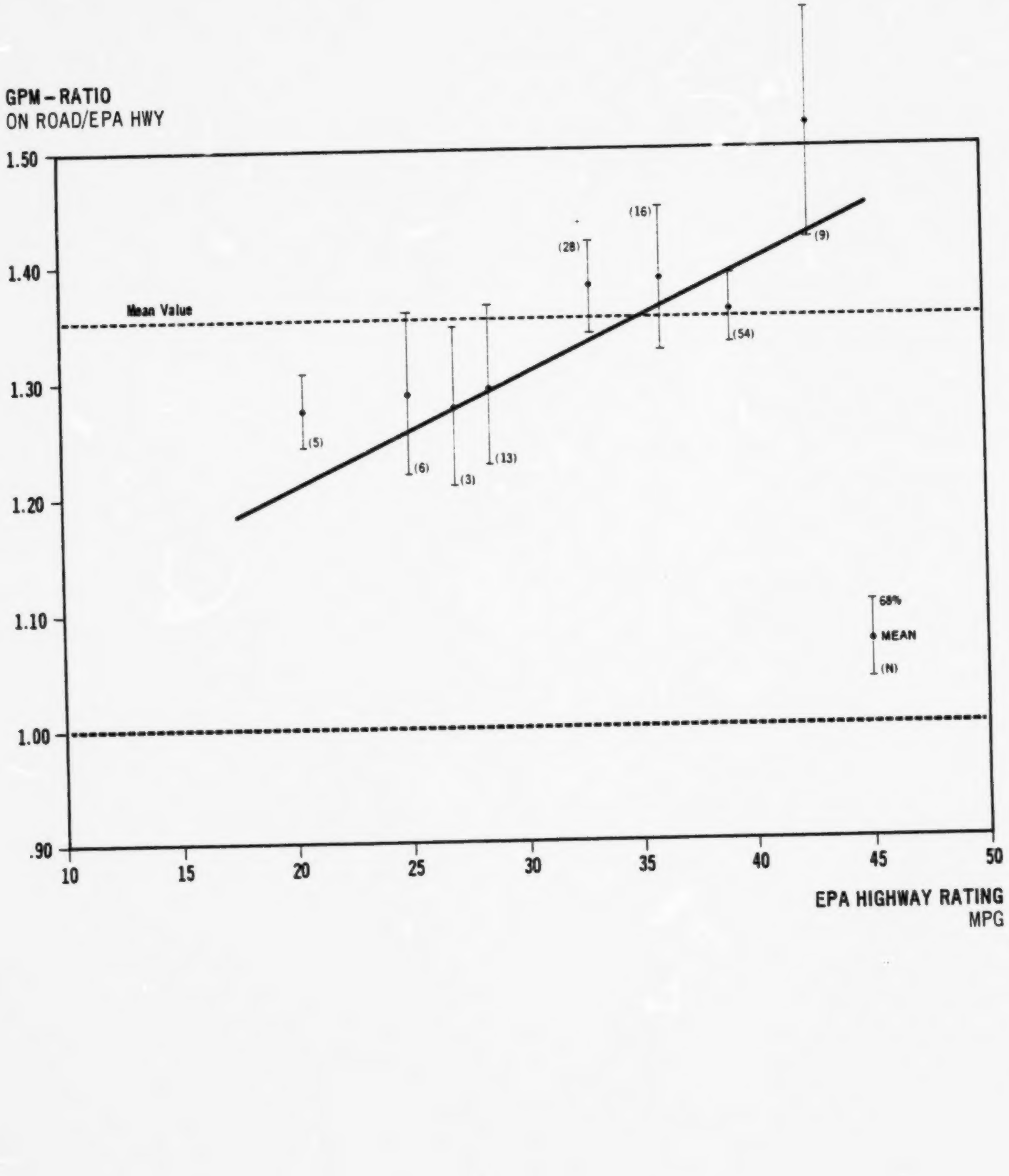


FIGURE 6–6

HIGHWAY DRIVING GROUP: RWD – CARBURETED MANUALS

URBAN PERCENTAGE ≤ 20%



Selection Criteria

EEA's judgment, based on examination of several alternate models for the city-driving subsets, is that no simple mathematical relationship is adequate to both represent existing data and to avoid very large adjustments for the higher-mpg vehicles not represented on the data base. The approach chosen here is to specify the EPA-dependence as linear functions which are bounded at the limits of shortfall observed in the data.

Figures 6-3 through 6-6 indicate that appropriate bounds for GPM-ratios at the high-mpg limit are approximately:

- 1.20 City
- 1.50 Highway

for both automatics and manuals. At the lower mpg limit, EEA believes that appropriate bounds are 1.00 for the city factor, i.e, no adjustment, and approximately 1.20 for the highway. These bounds will be re-assessed for the specific adjustment factors recommended in the next section, however.

In general, the low-mpg bounds will affect very few vehicles. Conclusive data do not currently exist that these cars perform better in city driving than over the urban cycle, although previous analyses often have shown a cross-over at the lowest EPA ratings. The lower bounds will become effective for the automatics rated at 10 mpg city or below and for manuals rated below 20 mpg, however, this will not be an issue for the higher mpg vehicles of the future.

The upper bounds on two-mode adjustment factors will be applied, however, to relatively large numbers of popular small cars and therefore, require careful consideration. The city factor of 1.20 is supported by the evidence showing a flattening of the shortfall line for automatics and represents a reasonable upper bound for manuals. Highway shortfall of

1.50 is found in both automatics and manual data sets and therefore, is not unreasonably high.

The primary real-world consideration in choosing the boundary factors is their adequacy for avoiding spurious labeling results, e.g., equal adjusted city and highway values. It is easily shown that given the chosen bounds on f_c and f_h, vehicles must achieve a highway to city ratio of at least 1.25 on dynamometer testing to be appropriately labeled. This criterion is applicable to automatics rated above 24 mpg city, 38 mpg highway, and to manuals rated above 35 city and 50 highway. Table 6-14 lists selected popular 1981 models fitting one of these criterion and presents the highway/city ratios achieved in EPA testing.

The table uses the linear relations of Tables 6-12 and 6-13, bounded as indicated above, to estimate approximate city and higway label values. The automatics are labeled with smaller city/highway differentials, as found for the constant adjustment factor systems. The Toyota Corolla automatic has a low dynamometer ratio and is given spurious label values. In general, however, the bounded linear relationships produce plausible labeling results. It is an unavoidable factor of the two-mode system that some vehicles will be poorly labeled. The EPA should, therefore, consider adopting an algorithm for re-adjusting the city or highway rating to achieve a minimum differential.

6.3.4 Model Specification

The foregoing results demonstrate that the two-mode adjustment factors should incorporate a (bounded) EPA-dependence in order to treat fairly and to satisfactorily label the cars at both low and high EPA ratings. The models chosen for this analysis assume linear dependence for the adjustment factors:

$$f_c = a_c + b_c C$$

TABLE 6-14

HIGHWAY/CITY RATIOS FOR SELECTED SUBCOMPACT CARS

	1981 Ratings		Dynamometer Ratio	Adjusted Label Values	
Model	City	Highway		City	Highway
Toyota Starlet (M5)	39	54	1.38	32.5	36.0
Chevrolet Chevette (A3)	26	33	1.27	21.7	22.8
Datsun B-210 (A3)	29	37	1.28	24.2	24.9
Mazda GLC (M4)	35	43	1.23	29.2	30.4
Toyota Corolla (A3)	27	32	1.19	22.5	22.5
Toyota Corolla (M4)	30	40	1.33	25.0	28.6
Toyota Corolla (M5)	28	39	1.39	23.3	28.0

$$f_H = a_H + b_H H$$

and the structure of the quadratic $\beta(u)$ models examined in Section 6.3.2.

The general form of the full adjustment factor model is therefore:

$$\beta(u) = a_H + (a_c^* - a_H) u + qu^2 + b_c uC + b_H (1-u) H$$

The city and highway factors themselves are determined by evaluating the regression equation at u = 1.00 (city) and u = 0.0 (highway):

$$f_c = a_c^* + q + b_c C \qquad \text{where} \qquad a_c = a_c^* + q$$

$$f_H = a_H + b_H H$$

The equations above are general relationships derived from the full model; however, not all coefficients are statistically significant in every instance. For example, as found for the constant adjustment factor system, the quadratic term in u is not significant for 1978 automatics or for the manual vehicles and so has been omitted from their analysis.

The final analysis has quantified separate two-mode factors for the four groups of 1978 and 1979 automatic and manual vehicles. The manual data sets are small and do not meet the target sample size criteria as already noted. While aggregating the 1978 and 1979 manuals produces greater statistical precision, the resulting adjustment factors do not reflect more accurately the real-world shortfall of the current vehicles, since the test procedures and model years are not directly comparable. Therefore, the recommended manual factors are based on the 1979 data alone.

In addition, highway adjustment factors for manuals have been treated as constants in the final analysis, since the smaller model-year data sets will not, in practice, determine all coefficients of the full $\beta(u)$ model. This forces the omission of the H term from the analysis of manual cars.

The regression models vary by model year and transmission type, as discussed above, due to the specific data requirements and limitations in each group. The final regression analysis has used the following models, which were chosen to include the statistically significant terms (at the 0.05 level) with greatest explanatory power:

- 1978 Automatics

$$\beta(u) = a + bu + b_c uC + b_h (1 - u) H$$

$$f_c = a + b + b_c C$$

$$f_h = a + b_h C$$

- 1979 Automatics

$$\beta(u) = a + bu + qu^2 + b_c uC + b_h (1 - u) H$$

$$f_c = a + b + q + b_c C$$

$$f_h = a + b_h H$$

- 1978 and 1979 Manuals

$$\beta(u) = a + bu + b_c uC$$

$$f_c = a + b + b_c C$$

$$f_h = a$$

The next section presents the recommended two-mode factors and appropriate bounds for the 1978 and 1979 automatic and manual transmission vehicles.

6.4 RECOMMENDED TWO-MODE FACTORS

This section summarizes the two-mode adjustment factors developed to quantify the dependence of shortfall on both the city/highway driving mix and the EPA rating of vehicles. As part of a real-world labeling system, its factors must be bounded appropriately when extrapolated beyond the EPA range of the current data base. The system also will poorly label a small number of vehicles at the higher mpg ratings. The following discussion presents the recommended factors and evaluates their accuracy and effectiveness in labeling.

Table 6-15 summarizes the regression statistics for the four adjustment factor expressions. These have been chosen to incorporate the linear-dependence of shortfall on EPA rating, and produce adjustment factor expressions with accurately known coefficients. The city and highway adjustment factors are the following:

- 1978 Automatics

$$f_c = 0.845 + 0.0136\ EPA_{city}$$

$$f_H = 1.127 + 0.0096\ EPA_{Hwy}$$

- 1979 Automatics

$$f_c = 0.963 + 0.0091\ EPA_{city}$$

$$f_H = 1.144 + 0.0088\ EPA_{Hwy}$$

- 1978 Manuals

$$f_c = 0.591 + 0.0208\ EPA_{city}$$

$$f_H = 1.312$$

- 1979 Manuals

$$f_c = 0.557 + 0.0166\ EPA_{city}$$

$$f_H = 1.343$$

Figures 6-7 and 6-8 illustrate the adjustment factors.

EEA judges that the analyses based on the 1979 data are most appropriate to be labeling of future new car fleets. As the preliminary analysis indicated, the city shortfall for automatics appears to obey a curvilinear relationship, with shortfall stabilizing beyond 25 mpg city. This is reflected in the lower slope of the 1979 city line in Figure 6-7, since the sample contains more vehicles above 25 mpg and fewer

TABLE 6-15

SUMMARY OF TWO-MODE ADJUSTMENT FACTOR MODELS

(RWD-Carbureted Vehicles)

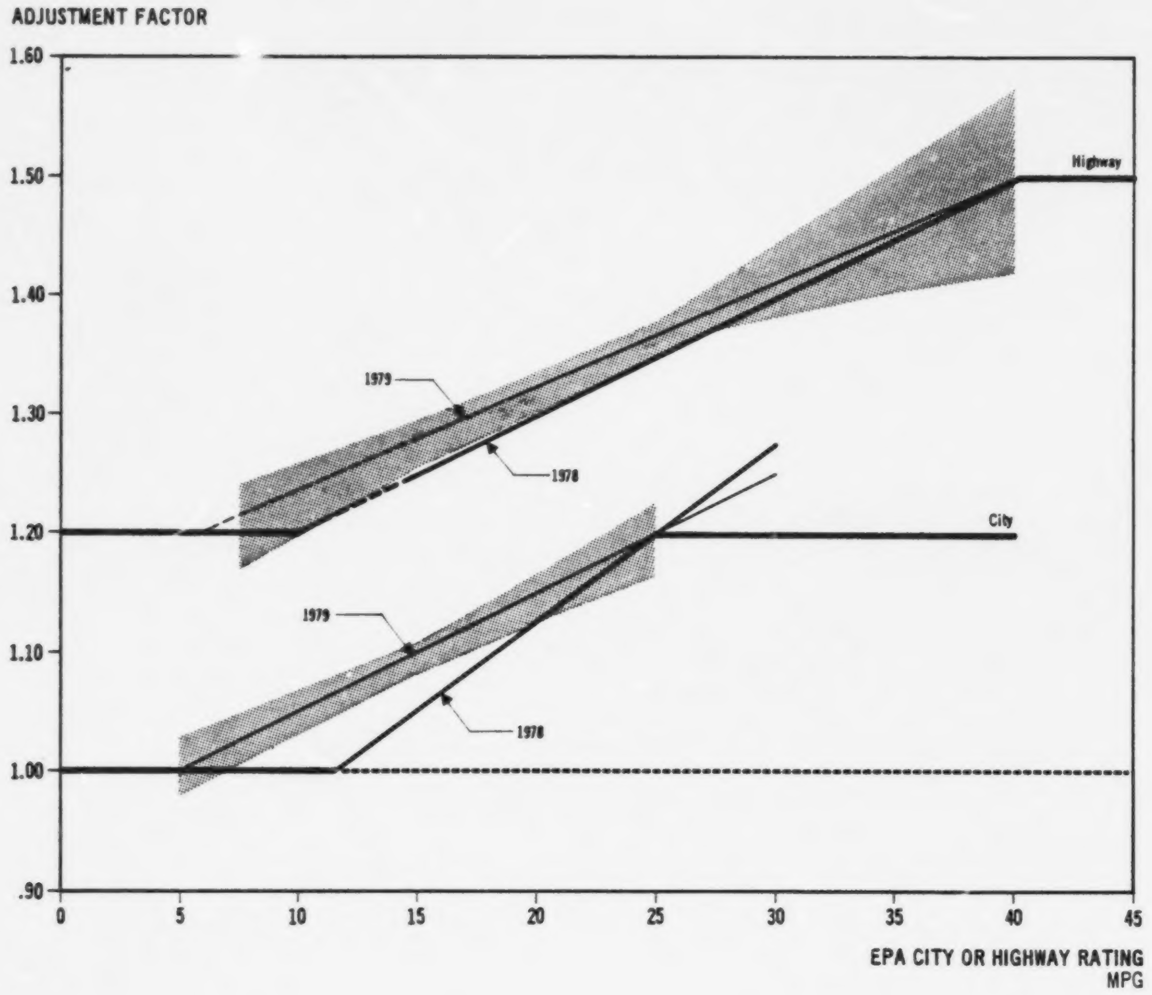
Technology	Model	N	R^2	a	(SE)	b	(SE)	q	(SE)	b_c	(SE)	b_H	(SE)
1978 Automatics	$\beta = a + bu + b_c uC + b_H (1-u) H$	1711	0.155	1.127	(0.080)	-0.282	(0.123)	--	---	0.0136	(0.0037)	0.0096	(0.0033)
1979 Automatics	$\beta = a + bu + qu^2 + b_c uC + b_H (1-u) H$	2177	0.150	1.144	(0.067)	-0.440	(0.124)	0.259	(0.059)	0.0091	(0.0037)	0.0088	(0.0028)
1978 Manuals	$\beta = a + bu + b_c uC$	313	0.137	1.312	(0.022)	-0.721	(0.111)	---	---	0.0208	(0.0043)	---	---
1979 Manuals	$\beta = a + bu + b_c uC$	276	0.261	1.343	(0.025)	-0.786	(0.128)	---	---	0.0166	(0.0049)	---	---

Note: (SE) denotes standard error or estimate

FIGURE 6–7

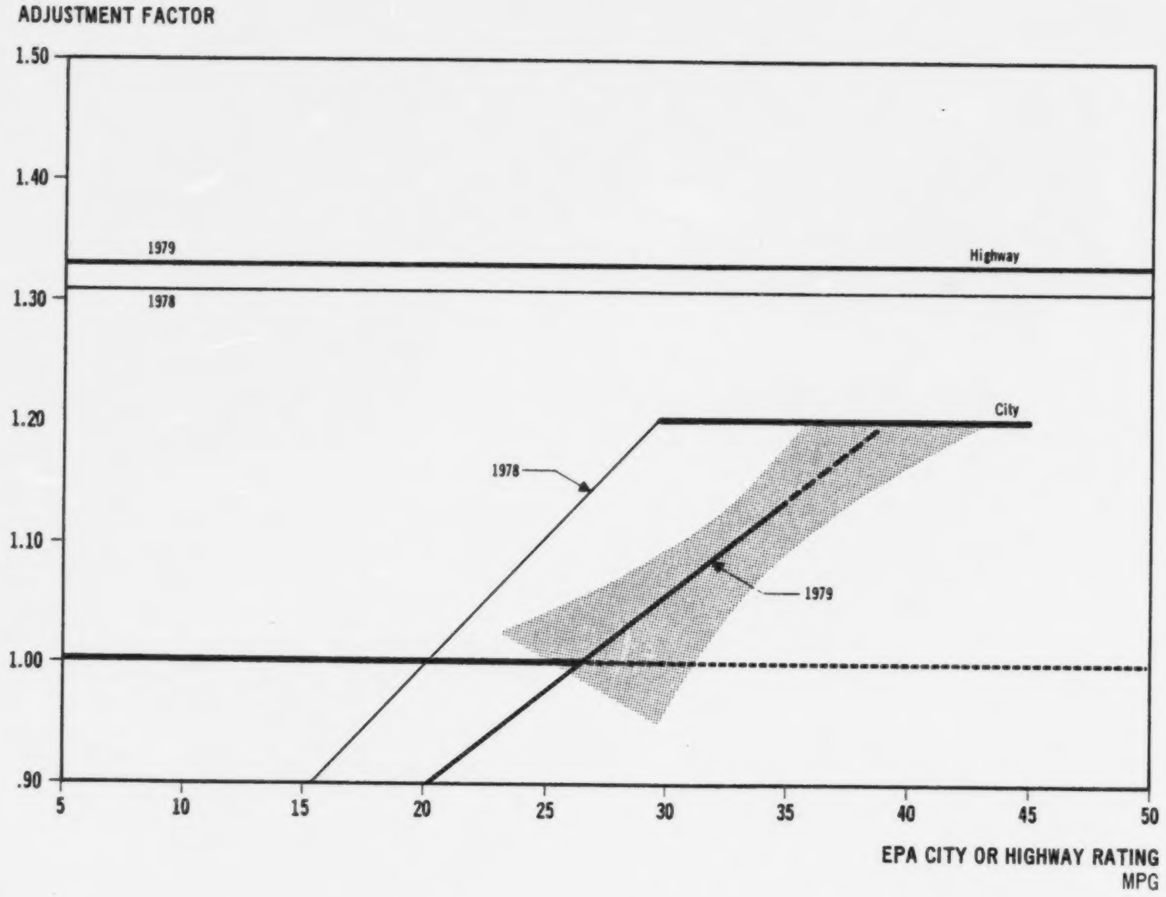
TWO-MODE ADJUSTMENT FACTORS

RWD – CARBURETED AUTOMATICS



NOTE: 95% Confidence Limits Shown for 1979 Relationships Only

FIGURE 6–8
TWO-MODE ADJUSTMENT
RWD – CARBURETED MANUALS



NOTE: 95% Confidence Limits Shown for 1979 Relationships Only below 15 mpg, compared to the 1978 data. Figure 6-8 clearly demonstrates the influence of 1979 test procedure changes in manual shortfall. Although the 1979 manual data base falls short of the recommended 625 sample size, an aggregate 1978-1979 analysis will penalize future vehicles for the past inaccuracies in the dynamometer test procedures.

The figures also indicate the bounds appropriate to the real-world application of the adjustment factors. Limiting the city adjustment to 1.20 is supported by the data for automatics and also is a reasonable bound for manuals, although the current data have inadequate representation beyond 35 mpg city to demonstrate a trend. The highway adjustment of high-mpg manuals similarly should be restricted to 1.50, the largest shortfall observed in the data. Because constant highway adjustment factors are specified for manuals, no bounding considerations apply.

The adjustment factors have been bounded at 1.00 in the lower-mpg rating. Smaller factors represent a gain above the urban-cycle test result and cannot be conclusively demonstrated for these technology groups. The data do indicate, however, that the 1979 test procedures changes have reduced city shortfall for manuals to approximately five percent. Manuals below 20 mpg city (sample size of nine) have a mean GPM-ratio of 0.90 and may be subject to a small penalty on urban-cycle. Current data do not permit further evaluation, however.

Evaluation of the Recommendations

The adjustment factor model is evaluated in Table 6-16 in terms of its accuracy in predicting fuel economy. This measure is independent of how well the systems label vehicles, but instead indicates what variation in on-road fuel economy is not accounted for. As seen in the table, 60 to 65 percent of automatic vehicles get within two mpg of the value predicted by the regression model for the reported city/highway driving mix

TABLE 6-16

EVALUATION OF RECOMMENDED ADJUSTMENT FACTOR SYSTEMS: ACCURACY IN PREDICTING FUEL ECONOMY

(percent of sample)

RWD-Carbureted Vehicles Difference: Reported MPG - Predicted MPG

Technology	N	<-3	-2	-1	0	1	2	>3
1978 Automatics	1711	23.7	12.0	13.3	14.3	11.7	8.5	16.5
1979 Automatics	1711	20.7	13.2	14.5	15.4	12.6	8.6	14.9
1978 Manuals	313	28.4	8.0	11.8	14.7	9.0	7.0	21.1
1979 Manuals	286	32.2	9.4	10.1	9.1	7.7	6.6	24.8

and the EPA ratings of the vehicle. Manual fuel economy is again more variable, although 50 to 55 percent of vehicles achieve a fuel economy within two mpg of the prediction. The regression model accounts for much of the variation in on-road fuel economy, with the remaining elements -- associated with the driver and local conditions -- not essential to a labeling system.

The more important measure is how well the adjusted city and highway label values reflect owner experience and whether they provide appropriate and meaningful city and highway fuel economy estimates. Tables 6-17 and 6-18 evaluate the adjusted label values in these terms.

Table 6-17 compares the on-road fuel economy estimates of the Power samples with the adjusted city and highway label values developed from the recommended factors and bounds shown in Figures 6-7 and 6-8. Among all drivers, 30 to 50 percent will find the city to highway range as an accurate estimate of what fuel economy they can expect. Approximately 10 to 20 percent of drivers will fall three or more mpg below the adjusted city value and, therefore, have cause for dissatisfaction. In city driving conditions, owners will typically achieve at least the city value and only 20 percent will be three or more mpg below. Among highway drivers, approximately 45 percent will get better fuel economy than the highway label value; the typical highway driver will find the highway value to accurately estimate real-world performance.

The recommended adjustment factors also provide meaningful ranges of city and highway values, as shown in Table 6-18. Automatics will typically have a two mpg range, while manuals will be labeled with a two to five mpg differential. The two-mode labeling system, adjusted to on-road fuel economies, can therefore be expected to provide consumers accurate and meaningful fuel economy estimates.

TABLE 6-17

EVALUATION OF RECOMMENDED ADJUSTMENT FACTOR SYSTEMS: COMPARISON OF ON-ROAD FUEL ECONOMY WITH LABEL VALUES

(RWD-Carbureted Vehicles)

	N	Percent Below City Value				Within City/ Highway Range	Percent Above Highway Value			
		Total Below	3+ mpg	2 mpg	1 mpg	City/Highway	1 mpg	2 mpg	3+ mpg	Total Above
All Drivers										
1978 Automatic	1711	28.5	11.3	7.5	9.7	35.9	11.2	9.3	15.0	35.5
1979 Automatic	2177	19.7	6.2	5.7	7.8	40.5	11.9	11.6	16.3	39.8
1978 Manual	313	19.4	10.5	3.5	5.4	53.0	8.0	3.5	16.0	27.5
1979 Manual	276	30.4	18.8	6.2	5.4	31.2	5.8	4.7	27.9	38.4
City Drivers (u >80%)										
1978 Automatic	356	38.2	21.1	8.7	8.4	34.0	8.1	8.7	11.0	27.8
1979 Automatic	381	34.1	13.4	8.9	11.8	38.1	10.0	7.3	10.5	27.8
1978 Manual	48	27.2	18.8	2.1	6.3	54.2	6.3	2.1	10.4	18.8
1979 Manual	39	48.7	28.2	7.7	12.8	23.1	7.7	5.1	15.4	28.2
Highway Drivers (u < 20%)										
1978 Automatic	449	18.3	4.7	4.2	9.4	34.7	14.0	13.8	19.2	47.0
1979 Automatic	637	13.5	3.1	4.7	5.7	40.2	14.6	14.4	17.3	46.3
1978 Manual	84	8.4	2.4	3.6	2.4	56.0	4.8	6.0	25.0	35.8
1979 Manual	59	27.2	15.3	6.8	5.1	30.5	6.8	6.8	28.8	42.2

Note: Figures may not add to 100 percent due to rounding.

TABLE 6-18

EVALUATION OF RECOMMENDED TWO-MODE ADJUSTMENT FACTORS: SPREAD IN CITY/HIGHWAY LABEL VALUES

(percent of sample)

RWD-Carbureted Vehicles

		Diference: Highway - City (mpg)							
Technology	N	<0	0	1	2	3	4	5	6
1978 Automatic	1711	0.2	3.6	26.1	66.5	3.3	0.3	--	--
1979 Automatic	2177	0.3	3.2	19.0	55.4	18.9	3.3	--	--
1978 Manual	313	1.0	5.4	4.2	4.2	25.9	37.4	22.0	--
1979 Manual	276	1.8	3.3	14.1	48.2	14.1	15.6	2.5	--

Inherent in this labeling system is the potential for the adjusted city and highway values to be equal or for the calculated highway fuel economy to be less than the city value. Table 6-19 lists the models in the Power data base which are poorly labeled by the recommended factors. These are predominantly small cars, made by both foreign and domestic manufacturers, with EPA city ratings above 24 mpg. The spurious labeling results are caused in part by the round-off error of using integer EPA ratings of the Gas Mileage Guide. In addition, very little data is available on the smaller vehicles, compared to the preponderance of mid-size and larger cars. Accordingly, the adjustment factors will provide poorer representations for the subcompact cars. In a real-world labeling system, on-road estimates derived from adjustment factors may require ad-hoc modification to provide a meaningful and useful range of fuel economy.

Manufacturer Differences

In an industry-wide basis, the two-mode labeling system described above is very effective in adjusting dynamometer tests results to on-road fuel economy. Its effectiveness stems from providing accurate fuel economy estimates for both city and highway drivers when viewed from the consumer perspective as a whole. Since the vehicles produced by the auto industry vary widely in size, fuel economy range, and market segment, a potential exists for the labeling system to produce less satisfactory results for selected groups of consumers. These differences may occur when specific manufacturers or vehicle types are not represented in the data. They also may occur if substantial differences in shortfall exist for one or more manufacturer. While the two sources of manufacturer-specific bias are different, their effects on the credibility of the labeling system are related.

In the first source of bias, adjustment factors are applied to vehicles not represented in the data. These include the low-mpg cars produced by

TABLE 6-19

SUMMARY OF MODELS POORLY LABELED BY RECOMMENDED FACTORS

Model Year	Transmission	Model Name	Label Differential (mpg)
1978	Automatics	Datsun B-210	0
		Datsun 510	-1
		Ford Pinto	0
		Mazda GLC	-1
		Toyota Celica	0
		Toyota Corolla	0
		Toyota Corona	0
1978	Manuals	Ford Mustang II	0
1979	Automatics	Chevrolet Chevette	0
		Datsun B-210	-1
		Datsun 510	-1
		Pontiac Firebird	-1
1979	Manuals	Chevrolet Chevette	0
		Chevrolet Monza	0
		Datsun B-210	0

Rolls Royce, Ferrari, and other manufacturers. Because the recommended two-mode system included lower bounds, these vehicles will have small or no adjustment to their dynamometer test results. Such specialized vehicles are not competitive in the fuel economy market and will suffer little or no competitive loss due to the adjustment factor system. Further, implementing the option for manufacturer-specific adjustment factors will offer these manufactuers relief in the event they can demonstrate inequitable treatment.

The much greater concern for fairness is whether the high-mpg car is properly represented by the recommended factors. Since the existing data base has a small sample of RWD-carbureted vehicles above 25 mpg, the trends in the two-mode analysis largely have been determined by the domestic vehicles between 15 and 25 mpg. Evidence presented in this and the previous chapter suggests that shortfall stabilizes above 30 mpg. With the exception of the Chevrolet Chevette and Monza, the higher-mpg (above 25 mpg for automatics, 30 mpg for manuals) vehicles in the data are produced by Japanese manufacturers. These Japanese vehicles have lower shortfall (on a percentage basis) than the 1978-1979 Chevettes, but because of limited data, separate adjustment factors cannot be developed for them. Also, the analysis cannot establish the reasons or causative factors for the lower shortfall and cannot predict whether future high-mpg vehicles from all origins will follow the trend of the Japanese models analyzed.

Under these conditions, developing a practical system for fuel economy labeling has required bounding the linear adjustment factors at the shortfall levels substantiated by the data -- 1.20 city, 1.50 highway. The chosen bounds represent conservative estimates in that they likely will not overestimate on-road fuel economy. The first issue examined here is whether the bounded adjustment factors treat fairly all manufacturers.

This question has been investigated by comparing the observed shortfall for each vehicle to the estimated shortfall derived from weighting the adjusted city and highway label values to the respondents' reported urban driving fraction. The EPA rating for this comparison is the re-weighted composite of urban and highway cycle test results. The residual shortfall is defined as:

$$\Delta = \frac{r_i - f_c c_i u - f_H h_i (1-u_i)}{c_i u_i + h_i (1-u_i)}$$

and measures how well the on-road label values fit the experience of each respondent. When compared on this basis, the mean differences by manufacturer provide a relative ranking which controls for the differing levels of fuel economy and the potential for differences in vehicle use.

As shown in Table 6-20, differences do exist by manufacturer, although they are small except for the Japanese. The comparison considers only the vehicles given meaningful label values and so excludes those listed in Table 6-19. The comparison also is relative; since GM vehicles constitute the large majority of data on RWD-automatics, the analysis has represented their performance well. The manual adjustment factors also provide appropriate labeling for the Japanese vehicles since these contribute approximately 25 percent of the data.

All manufacturers show less automatic shortfall than predicted by the bounded two-mode factors, because the analysis slightly underpredicts fuel economy and the bounds are employed to modify the regression results. The differences are statistically significant at the 0.05 level for AMC, Ford, and the Japanese, representing 1 to 2 mpg for the domestics and 5 mpg for the Japanese. The differences are therefore substantial.

Among the manual transmission vehicles, comparisons are appropriate only for Ford, GM, and the Japanese due to the distribution of the sample. Again Ford is penalized by approximately 1 mpg, while GM benefits by

TABLE 6-20

COMPARISON OF OBSERVED AND PREDICTED SHORTFALL BY MANUFACTURER

(RWD-Carburetted Vehicles)

1979 Vehicles	Total Sample Size	Vehicles Excluded*	Harmonic Mean EPA Composite (mpg)	Mean GPM-Ratio β (observed)	(SE)	Mean Difference (observed-predicted)	(SE)
AMC	37	0	20.2	1.137	.036	-.104	.030
Chrysler	121	2	19.6	1.217	.023	-.027	.021
Ford	472	0	17.6	1.155	.011	-.057	.010
GM	1729	75	19.6	1.224	.005	-.007	.005
Japanese	89	13	29.5	1.151	.032	-.071	.031
Automatic							
AMC	31	0	19.7	1.149	.035	-.103	.031
Chrysler	109	0	18.8	1.232	.025	-.014	.023
Ford	419	0	17.1	1.162	.012	-.056	.011
GM	1586	67	19.2	1.222	.006	-.013	.005
Japanese	28	9	26.1	1.100	.040	-.223	.036
Manuals							
AMC	6	0	23.0	1.076	.142	-.106	.108
Chrysler	12	2	36.7	1.054	.045	-.174	.041
Ford	53	0	23.6	1.094	.022	-.068	.022
GM	143	8	27.4	1.249	.020	.066	.017
Japanese	61	4	30.8	1.168	.041	-.020	.037

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*Vehicles poorly labeled by recommended adjustment factors (see Table 6-19).

2 mpg. The manual sample for the domestics consists largely of the Ford Pinto/Bobcat and the GM Chevette and Monza, so that model-specific differences may be the source of the manufacturer bias. The Japanese are not penalized significantly.

Table 6-21 summarizes similar comparisons on a driving mode basis. Although the sample sizes are too small to support definitive conclusions, the city shortfall for GM's automatic vehicles is substantially above that of other manufacturers while highway shortfall is less different. The Japanese vehicles are penalized approximately 20 percent in both the city and highway label values for automatics. Note, however, that the city and highway subsets for Japanese cars are very small and, although the shortfall differences are statistically significant, may not be representative of larger samples. The differences displayed in these tables support the following conclusions:

(1) The sample's Japanese vehicles with automatics perform better on average than predicted by the label values. The two-mode system may therefore be less effective in providing accurate information for the buyers of these vehicles.

(2) Among domestic manufacturers, overall shortfall is lower for AMC and Ford than for GM. The difference is statistically significant at the .05 level and is greatest for city drivers, although only GM and Ford can be compared on this basis.

The differences for the Japanese vehicles are large enough to be of concern to the manufacturers and to the EPA. These vehicles will be labeled with fuel economy values below the on-road experience of many motorists, and may therefore be a source of dissatisfaction with the recommended system. The acquisition and submission of in-use survey data may therefore be a viable method of resolving this potential issue.

Because GM has the largest market share among manufacturers, the industry-wide analysis using sales-weighted data bases will likely provide appropriate adjustment factors for this manufacturer. Evidence exists that GM

TABLE 6-21

COMPARISON OF CITY AND HIGHWAY SHORTFALL BY MANUFACTURER

(RWD-Carburetted Vehicles)

1979 Vehicles	Sample Size*	Observed GPM Ratio β	(SE)	Predicted GPM Ratio β	(SE)	Difference Observed-Predicted Ratios	(SE)
Automatics							
City Drivers (u>80%)							
AMC	8	1.052	.064	1.139	.005	-.089	.065
Chrysler	14	1.076	.065	1.134	.003	-.058	.065
Ford	66	1.039	.025	1.120	.003	-.081	.025
GM	230	1.151	.013	1.137	.001	+.014	.013
Japanese	3	0.979	.092	1.178	.014	-.199	.092
Highway Drivers (u≤20%)							
AMC	10	1.257	.035	1.344	.005	-.087	.035
Chrysler	37	1.365	.033	1.330	.003	+.035	.032
Ford	121	1.266	.020	1.305	.003	-.039	.020
GM	443	1.322	.010	1.325	.001	-.003	.010
Japanese	6	1.194	.059	1.405	.003	-.211	.058
Manuals							
City Drivers (u>80%)							
AMC	1	--	--	--	--	--	--
Chrysler	0	--	--	--	--	--	--
Ford	8	1.036	.044	1.027	.004	+.009	.045
GM	20	1.080	.036	1.053	.004	+.027	.033
Japanese	5	1.059	.072	1.037	.011	+.022	.068
Highway Drivers (u≥80%)							
AMC	1	--	--	--	--	--	--
Chrylser	2	--	--	--	--	--	--
Ford	11	1.179	.063	1.315	.007	-.136	.064
GM	28	1.406	.036	1.311	.005	+.095	.036
Japanese	14	1.362	.084	1.329	.006	+.033	.085

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*Excludes vehicles poorly labeled (see Table 6-19).

vehicles have a 6 to 9 percent larger shortfall than cars produced by AMC or Ford. These results are statistically significant within the sample, but it must be noted that the Power data base does not meet all specifications recommended to the EPA for establishing manufacturer-specific labeling. Importantly, the recordkeeping quality of the owner estimates used in this analysis can influence results by as much as seven percent compared to fuel purchase data. Differences seen among the manufacturers must therefore be viewed as indications of trends and not as conclusive.

6.5 ALTERNATIVE TECHNOLOGIES

The vehicles of future model year fleets will contain much higher proportions of the alternative technologies than the model years for which on-road data have been collected. Front-wheel drive, in particular, is expected to become a dominant drive-train technology, although the penetration of fuel injection systems (primarily throttle-body fuel injection) and diesel engines also are expected to increase substantially. The two-mode adjustment factors developed earlier in this report for the RWD-carburetted vehicles will therefore be of diminished usefulness in future years. All the data available on alternative technologies indicate they have very different shortfall performance and will be improperly labeled by the adjustment factors for conventional vehicles.

This section examines the current data and quantifies constant city and highway adjustment factors for the technology combinations which can be expected to differ on an engineering basis. The data also include four model lines with sufficient representation to justify model-specific analyses. Although the proposed two percent uncertainty can be met only for the Ford Fiestas, the model-to-model comparison of two-mode factors provides an estimate of the validity of results for more aggregate groups.

An initial constraint is that separate two-mode factors currently are not possible for diesel vehicles, since the small diesel data base has been drawn primarily from sources which do not provide estimates of the urban driving percentage. The major difference seen among alternative technologies is that of FWD versus RWD, and these aggregate technology groups include both gasoline and diesel engines. A further constraint is that the categorization of the technology groups is ad hoc. The groups span in some instances very different vehicles which have shown differences in composite shortfall in the analysis of Section 5. With the exception of data eliminated because the specific technologies are unrepresentative of current and future vehicles, all data on the alternative technologies have been divided into the following categories:

- Front-wheel drive, carbureted cars with manual transmissions (FWD/CARB/MANUAL)
- Front-wheel drive, carbureted cars with automatic transmissions (FWD/CARB/AUTO)
- Front-wheel drive, fuel-injected (FWD/FI)
- Rear-wheel drive, fuel-injected gasoline or diesel vehicles (RWD/FI)

The aggregation provides an adequate sample size for the two-mode analysis, although the target 2 percent uncertainty can be achieved only for the group containing Ford Fiestas. The limitations of the available data mean that the adjustment factors may not be representative of the performance of each model within groups.

The data eliminated from the analysis consist of the older front-wheel drive technology (non-transverse) used in Oldsmobile Toronados, Buick Rivieras, and carbureted Cadillac Eldorados, and the pre-1979 Ford Fiestas and Honda vehicles with manual transmissions. The General Motors vehicles are not in production today and are much larger and heavier than the vehicles which have replaced them. They also are not representative of the more typical applications of FWD. The pre-1979 Ford and Honda vehicles have been made untypical of current vehicles by the 1979 test procedure changes. As identified in the single-mode analysis, these particular vehicles showed large decreases in shortfall from 1978 to 1979, primarily as a result of changes in the EPA dynamometer ratings and not through substantial improvements in on-road performance. A review of the data by model year and model line indicated that the FWD/CARB/MANUAL vehicles of other manufacturers experienced no comparable effects and, in fact, had an on-road shortfall approximately equal to the later (1979-1980) Fiestas and Hondas. These other vehicles have therefore been retained.

Because the on-road surveys conducted by the Ford Motor Company contain relatively large samples of Fiestas, compared to other sources, this analysis can develop city/highway adjustment factors at the target 2 percent uncertainty level. Although this vehicle is not now in production, and the resulting adjustment factors therefore not applicable to a current vehicle, the capability for model-specific analysis eliminates the confounding due to pooling of data and permits an unambiguous determination of one set of two-mode factors. The other models for which analysis is possible are the rear-wheel drive 1980 Lincoln Continental and Marks, equipped with the Ford throttle-body fuel injection (TBFI) system, the 1978-1979 Dodge Omni and Plymouth Horizon, and the 1978-1979 Volkswagen Rabbit (gasoline) with multi-point fuel-injection.

The two-mode adjustment factors summarized in Tables 6-22 and 6-23 have been developed through the constant adjustment factor model

$$\beta = a + b \cdot u$$

where u is the urban driving fraction and β the re-weighted GPM-ratio. The methodology follows that presented in Section 6.3 for constant adjustment factors.

TABLE 6-22

CONSTANT ADJUSTMENT FACTORS FOR SPECIFIC MODEL LINES

Model	N	Mean GPM-Ratio	(SE)	City Factor	(SE)	Highway Factor	(SE)
1980 Ford Fiesta	171	1.0345	.0088	.854	.019	1.195	.018
1978-1979 Omni/ Horizon (Automatic)	91	1.054	.018	.913	.039	1.161	.032
1978-1979 Omni/ Horizon (Manual)	111	1.097	.015	.910	.034	1.221	.025
1978-1979 Omni/ Horizon (All)	202	1.076	.012	.910	.026	1.196	.020
1978-1979 VW Rabbit FI(GAS)*	117	1.069	.016	.888	.035	1.203	.028
1980 Lincolns (TBFI)	227	1.188	.012	1.038	.025	1.348	.026

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*97 vehicles equipped with manual transmissions

Note: (SE) denotes standard error

TABLE 6-23

CONSTANT ADJUSTMENT FACTORS FOR ALTERNATE TECHNOLOGY GROUPS

Technology Category	N	Mean GPM-Ratio	(SE)	GPM City Factor	(SE)	GPM Highway Factor	(SE)
FWD/CARB/MANUAL	380	1.057	.0072	.872	.016	1.206	.014
FWD/CARB/AUTO	98	1.052	.016	.922	.036	1.154	.030
FWD/CARB/ALL	478	1.0561	.0068	.883	.015	1.194	.012
FWD/FI(GAS)	129	1.075	.015	.877	.033	1.219	.027
ALL FWD(GAS)	607	1.0601	.0062	.881	.013	1.200	.011
RWD/FI (GAS AND DIESEL)	269	1.193	.012	1.021	.024	1.371	.024

*Note: Does not include pre-1979 Ford Fiesta and Honda vehicles with manual transmissions.

As seen in Table 6-22, the front-wheel drive technologies have approximately 7 percent shortfall overall compared to the 18 percent of the Lincolns and the 18-20 percent typical of conventional automobiles. The similarity of adjustment factors for the FWD vehicles suggests very strongly that FWD is the dominant technology. The city factors range from 0.85 to 0.91, with the lowest (.854 for the Fiesta) being marginally different from that of the Omni/Horizons. The transmission type has no effect on the Omni/Horizon city factor and only a small effect on the highway factor. The data indicate that an aggregate FWD factor applied to subcompact cars is appropriate. Note also that the 1980 test procedure changes were not in effect for the pre-1980 Omni/Horizons and the VW Rabbits and may in part explain their slightly higher city factors.

These vehicles perform approximately 10 percent better in on-road city conditions than on the urban-cycle dynamometer test. The data for the Ford Fiestas is adequate to quantify the city factor to within a 2 percent standard error and should be judged conclusive evidence that the city label values for this vehicle required adjustment to higher fuel economy. The highway factor also meets the target accuracy. In all FWD models, the city factors are statistically different from 1 at the .05 level and indicate this class of vehicles is penalized on the urban-cycle test.

The 1980 Lincolns are rear-wheel drive vehicles and show substantially different shortfall performance than the FWD cars. These vehicles were rated at 17 mpg city, 24 mpg highway, in 1980, and have an average on-road performance of 16.4 mpg city, 20.2 highway. The city factor is not statisticaly different from 1.00 (no shortfall) and is approximately 6 percent below the factor recommended for RWD-carburetted cars. It is, however, not statistically distinguishable from the RWD-carburetted adjustment factor line. The Lincoln highway factor similarly is not different from that recommended for the RWD-carburetted cars. The data therefore do not indicate a decrease in shortfall attributable to the TBFI fuel system.

Table 6-23 presents the two-mode adjustment factors developed for aggregate categories of alternative technologies. The composition of the groups has been detailed in Section 5, although the sample size is smaller for this analysis, which requires estimates of the urban driving fraction. The FWD groups are dominated by the Fiestas, Omni/Horizons, and Rabbits so that the aggregate adjustment factors necessarily are similar. The Lincolns comprise the large majority of the RWD/FI group. The aggregate two-mode factors are therefore strongly influenced by the four model lines.

The model-specific results indicate that the aggregate FWD adjustment factors can properly be applied to gasoline-powered FWD subcompacts. At this time, two-mode factors cannot be developed for FWD in combination with diesel engines or for alternative rear-wheel drive technologies. The aggregate RWD/FI factors are based on 42 data points in addition to the 1980 Lincolns and should not be extrapolated to other dissimilar vehicles. Until further data become available, credible two-mode factors can not be implemented for diesel or RWD/FI vehicles.

6.6 SUMMARY

The analysis of this section has developed two-mode adjustment factors for several technology groups. The discussion of conventional technologies (i.e., rear-wheel drive, carbureted vehicles) substantiates the difference between automatic and manual transmission cars seen earlier in Section 5. In addition, the test procedure changes of the 1979 protocol served to reduce shortfall for manual vehicles. The data sets for model year 1979 vehicles are more representative of the future vehicle fleets than the 1978 data also examined.

Accordingly, the most appropriate two-mode adjustment factors for future labeling procedures are those summarized in Table 6-15 for the 1979 automatic and manual cars. These factors, with the associated bounds, are the following:

- RWD-Carbureted Automatics

City: $f_c = 0.963 + 0.0091 \cdot EPA_{city}$

where $f_c \geq 1.00$ and $f_c \leq 1.20$

Highway: $f_h = 1.144 + 0.0088 \cdot EPA_{Hwy}$

where $f_h \geq 1.20$ and $f_h \leq 1.50$

- RWD-Carbureted Manuals

City: $f_c = 0.557 + 0.0166 \cdot EPA_{city}$

where $f_c \geq 1.00$ and $f_c \leq 1.20$

Highway: $f_H = 1.343$

and no bounds apply to the constant factor

As noted above, these relationships are based on the analysis of 1979 data and therefore incorporate the effects of 1979 test procedure changes.

The analysis for alternative technologies demonstrates that the front-wheel drive vehicles examined have very different shortfall characteristics than the conventional vehicles. Table 6-22 summarizes the two-mode factors developed for the four model lines which can be analyzed with existing data. While the rear-wheel drive Lincolns equipped with TBFI cannot be distinguished from the aggregate relationship for RWD-carbureted vehicles, the FWD subcompacts perform better in city driving than on the EPA urban-cycle and have lower highway shortfall than rear-wheel drive cars of comparable EPA ratings. These results indicate that FWD subcompacts require technology-specific factors in an on-road labeling system.

Developing a comprehensive system of adjustment factors for vehicles not covered by the conventional-technology relationships requires more data than available to this study. Table 6-23 presents constant adjustment factors for several possible hierarchies of technology; however, it must be remembered that each generic group is composed largely of data on the four model lines examined earlier. For example, the FWD/CARB/ALL group is dominated by the Fiesta and the Omni/Horizon, which comprise 78 percent of the data for this generic category. Further, no data is available on diesel-powered vehicles, and very little on RWD-FI subcompacts.

As a result, the administrative determination of two-mode adjustment factors for generic categories will have to consider carefully the appropriateness of extending the factors developed here to vehicles not represented in the data base. Engineering insight may provide useful guidelines in applying the aggregate FWD factors to heavier vehicles such as the Seville. The complete resolution of these administrative issues will, however, require additional data and analysis.

REFERENCES FOR SECTION 6

1. Falcon Research and Development, "Individual Manufacturer Procedures to Establish Fuel Economy Adjustment Factors," Draft Final Report, prepared for the U.S. Environmental Protection Agency, Ann Arbor, MI, under contract 68-03-2835, Task Order No. 4, December 10, 1980.

2. _Ibid_, Section 4.

3. U.S. Environmental Protection Agency, Technical Support Report for Regulatory Action, "Light Duty Vehicle Fuel Economy Labeling." October 1980.

7. A REVIEW OF FUEL ECONOMY ESTIMATES PUBLISHED BY CONSUMER AND ENTHUSIAST PUBLICATIONS

7.1 INTRODUCTION

As a group, consumer and automotive enthusiast-oriented magazines sponsor a great deal of fuel economy testing. These magazines have, from time to time, published criticism of the EPA test procedure and could be considered partly responsible for the growth of public skepticism about the EPA fuel economy figures. This section examines the fuel economy test procedures used by selected enthusiast publications and evaluates the mpg values produced by their test methods relative to EPA fuel economy estimates.

Six magazines equally divided into two groups were chosen for this analysis:

Consumer Publications

- *Consumer Reports*
- *Consumers' Research*
- *Consumer Guide*

Automotive Enthusiast Publications

- *Motor Trend*
- *Car and Driver*
- *Road and Track*

Only those fuel economy test procedures usually included within the magazines' road tests will be assessed. The analysis is limited to road tests of automobiles from model years 1978 through 1980. Figures derived from fuel economy tests of high performance or luxury vehicles, such as Ferraris or Rolls Royces, are omitted because they are not representative of the normal automobile population and they are not reviewed in consumer magazines. Constraints of time and availability have prevented the inclusion of all published fuel economy test values, but the data collected are representative of all the available information.

The analysis will quantify the difference between magazine fuel economy estimates and EPA values for city, highway, and composite driving.

To evaluate trends in alternative mpg information available to the consumer, the difference between EPA and magazine values will be presented by magazine and test mode. In addition, selected popular models will be analyzed to illustrate the sensitivity of EPA versus magazine mpg differences to alternative magazine test procedures.

7.2 GENERAL MAGAZINE CONTENT AND PERSPECTIVE

The publications included in this study generally fall into one of two categories: 1) those which are consumer-oriented and 2) those that are oriented towards the automotive enthusiast. The consumer publications conduct automobile road testing with an interest that is distinctively different from that of the automotive enthusiast magazines. The consumer press views the automobile as a crucial tool vital to the normal flow of everyday living. The expense of this "tool" makes the purchase of such an investment worthy of lengthy comparison and deliberation. In the words of a Consumer Reports writer, "We devote most of our attention to safety, fuel economy, comfort, and convenience-practical information that helps the average driver decide which car to buy."[1/] Consumer publications weigh heavily those factors that relate to operational and maintenance costs, especially fuel economy and reliability. Emphasis on the fuel economy aspect of driving a car has forced the consumer publications, more than ever, to devote their attention and time to road testing those vehicles considered to be "fuel-savers."[2/]

It is important to note that the consumer magazines do not ignore performance statistics or styling. These elements are given considerable weight in assessments of safety and personal satisfaction.

Automobile enthusiast publications generally direct their copy to those readers who consider the automobile more than just a "means of transportation." Instead, a car represents a legitimate source of excitement and a reflection of personality. The uppermost interests of the enthusiast publications are the characteristics of power and style in automobiles. They road test numerous exotic cars (Lamborghini, Ferrari, Aston Martin, etc.) and regularly publish reminiscences and re-examinations of classic automobiles. Features on auto races and race car drivers are a staple. Yet, these magazines also have increasingly focused on the importance of fuel economy as a criterion for vehicle evaluation.

7.3 MAGAZINE FUEL ECONOMY TESTING

The magazines targeted for this study employ (or have employed) a variety of techniques to determine the fuel economy of test vehicles. To differentiate and compare the test methods, certain vital test elements will be examined and highlighted:

- Test course description
- Driving schedule
- Measurement techniques for miles driven and fuel consumed
- Acquisition of test cars
- Standardization of test cars prior to testing with respect to
    - motor adjustment
    - odometer mileage
    - tire inflation
- Fuel, weather, and seasonal factors.

Other characteristics that add to the elemental test method description will be included where necessary. Most of the information included in this description is derived from personal contacts with the publications, except in the case of Consumer Reports. The discussion of the Consumer Reports testing procedure is gleaned from actual road test articles because the magazine's staff declined to supplement published piecemeal information by either interview or correspondence.

7.3.1 Consumer Reports

To determine the fuel economy of an automobile, Consumers Union (the publisher of Consumer Reports) measures vehicle fuel consumption over three different drive cycles which represent:

- City driving mode
- Highway driving mode
- Mixed (combination of city and highway) driving mode.

The city mode test cycle simulates urban driving over a one-mile course. Each test vehicle follows an identical schedule of stop-and-go driving. The fuel consumption in this test, as in all other Consumer Reports fuel economy tests, is measured by a flow meter. The highway mode figure represents the fuel economy of a vehicle traveling at a constant speed of 55 mph. Consumers Union conducts this test on a relatively level 2.5 mile section of highway in New York. A test is conducted in both directions on the course to reduce the effects of wind and gradient, with the combined results being averaged to produce a fuel economy for operation at a constant 55 mph. The city and highway fuel economy figures are included in every Consumer Reports road test and road test review. The magazine also develops a mixed-mode fuel economy figure which results from vehicle operation over a 195 mile test cycle. The driving schedule is designed to include stop-and-go driving, suburban driving, and highway cruising. The 195 mile test fuel economy figure is included in all complete road test articles, but not in the annual compendium of road test reviews included in every April issue of Consumer Reports. Prior to 1979, Consumers Union also carried out additional constant speed fuel economy testing in its road tests. These figures are not considered here.

No information was discovered relating to the possible standardization of vehicles prior to testing. Nor was there any indication that variations in weather conditions and gasoline grades were accounted for in the test procedures.

Consumers Union is the only organization, in this analysis, that purchases its test cars directly from manufacturers' showrooms. The idea behind this policy is that cars will not be specially prepared by the manufacturers to perform well in the magazine's tests.

7.3.2 Consumers' Research

The test procedure used by Consumers' Research is significantly different from those used by other publications in this study. This magazine develops fuel economy figures for vehicles that are driven only at constant, relatively high speeds (usually 55 mph).

For a test course, the Consumers' Research staff utilizes one particular stretch of interstate highway in New Jersey about 30 miles from the magazine's editorial offices. The road is relatively unoccupied and level, promoting testing consistency.

To perform the fuel economy test, the automobiles are fully warmed up and are cruising at test speed at the beginning of the course. At that point, each vehicle is allotted one-tenth of a gallon of gasoline, as measured by a flow meter, and operated until the allotment is consumed. The odometer-measured distance is totaled after four test runs (two runs in each direction to minimize effects of wind and grade). The test is usually run at 55 mph, although the staff occasionally will run additional tests at 45 mph if their time permits. The speed at which the test was run is published in the road test article included with the report of the fuel economy figure(s). To calculate the car's fuel economy, the total distance for the four runs is multiplied by an odometer correction factor* and divided by four gallons. The result is rounded to the nearest 0.5 mpg. The magazine always publishes a 55 mph fuel economy figure and occasionally includes a 45 mph figure.

The cars tested by Consumers' Research are usually on loan from manufacturers' public realtions offices, although rented cars are tested frequently. The cars are tested in the condition that they are received. Tire pressures are adjusted to recommended levels and each vehicles is tested with a load of 450 pounds, including driver, assistant, and test equipment. There is no attempt made to standardize the odometer reading of test vehicles at the time of testing. Most vehicles tested will have accumulated readings between 1500 and 5000 miles at that point. Other uncontrolled factors are fuel, which is purchased where convenient, and weather, although the staff does avoid testing on cold, windy, or snowy days. Most testing for a particular model year is carried out from late fall, following vehicle introduction, into late spring of the next year.

7.3.3 Consumer Guide

Consumer Guide does not use a specific test course to test automobile fuel economy. Instead, test vehicles are driven over the period of a few weeks in the Chicago area. Records of gasoline consumed and miles driven are kept and used to calculate fuel economy at the end of the general driving period. Driving is carried out by two staff members, each driver having the car for a period of one week. The split between city mode and highway mode driving is approximately two-thirds city to one-third highway. The fuel economy figure published in a road test report will be either of the following:

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* The accuracy of the odometer is determined by a separate test. Any discrepancy between odometer-measured mileage and actual mileage is computed and used to produce an odometer correction factor. This enables the testers to accurately measure the distance traveled in the fuel economy test. Most magazines in this study tested the accuracy of vehicle odometers.

- The observed city/highway split, or
- A single cumulative average representing mixed-mode fuel economy achieved over the duration of the test.

Test vehicles are borrowed from manufacturers' public relations offices. The cars are tested as received; no investigation is carried out to see if a vehicle meets specifications. The odometer accuracy is tested and appropriate corrections are made to the fuel economy calculations. Fuel consumption is measured according to gas pump figures -- no flow meter is involved. No special/single fuel is used during testing. Variable Chicago-area weather makes compensation for climatic conditions impossible, although adjustments are made for lengthy warm-ups on coldest days. Tests are performed all year long. The test cars generally have accumulated less than 5000 miles at time of testing, but there is no attempt to perform the tests at a standard odometer reading.

7.3.4 Motor Trend

Motor Trend maintains a single test cycle for all of its fuel economy testing. Test vehicles are driven around a timed, 73-mile test loop located in California according to a precise driving schedule. The cars are provided with a full tank of gasoline prior to testing and fuel consumption is determined by fuel pump measurement following the driving cycle. No flow meter is used. Fuel consumption is measured to a tenth of a gallon. Motor Trend publishes a single fuel economy figure derived from this 73-mile test. Because this test cycle represents mixed-mode driving (city and highway), it is interpreted as a "combined" driving figure in this study.

The cars begin the test cycle from a "cold start." Fuel variation is controlled by repeated purchasing at one service station for unleaded gasoline-fueled vehicles and one for diesel cars.

Vehicles are obtained through manufacturers' public relations channels and are tested in the condition that they are received. Test cars seldom have more than 2500 miles registered on the odometer at the time of testing. Because of the relatively constant nature of the California climate (warm, sunny weather), no weather-related accommodation is made in the fuel economy calculation. Also, testing is carried out year-round.

7.3.5 Car and Driver

Car and Driver changed its fuel economy testing policy during the period under consideration (1978-1980). In 1978 (including the testing of a few 1979 models), the fuel economy tests were conducted on a dynamometer much like the federal testing procedure. Car and Driver stopped performing dynamometer testing in 1979 for reasons of inconvenience, according to the magazine.[3/] From 1979 until November 1980, Car and Driver generally published only EPA generated fuel economy data. This included most of the 1979 models and all of the 1980 model year vehicles tested. In November 1980, Car and Driver began to conduct on-road fuel economy tests of vehicles. Thus, for the model years under investigation in this study, Car and Driver did not carry out on-road fuel economy testing.

7.3.6 Road and Track

Road and Track road test articles include fuel economy figures that reflect between two and four weeks of driving experience by staff writers. No precise test cycle or driving schedule is utilized in this testing. Records of gasoline purchases are maintained through the testing period. Total distance is determined according to the odometer reading and an odometer correction factor established in a separate test. Using these numbers, Road and Track calculates a single fuel economy figure which represents "normal" driving as described in its own terms. Because this cumulative average figure represents mixed-mode driving carried out over a long term, it is interpreted as a "combined" fuel economy figure in this study.

The test vehicles are acquired through manufacturers' district offices - the same public relations routes utilized by most of the other magazines in this study. Car are assumed to meet specifications and are tested as they are received, with no significant adjustment. The odometer of the test cars usually register between 1000 miles and 3000 miles at the time of testing. The staff does not try to standarize vehicle odometer readings at time of test.

Because fuel is bought with a company credit card, the location of purchase is usally limited to two service stations, both representing the same oil company. Road testing is carried out throughout the year. Since the fuel economy test involves vehicle operation over a lengthy time period, it is impossible to control weather variations. No accounting for weather variations is made in the fuel economy calculation. Finally, in characterizing the test carried out by Road and Track, the Automotive editor admits the driving tests reflect "spirited operation" by staff members.

The various magazine-generated fuel economy tests are summarized in Table 7-1.

7.4 DATA COLLECTION, ANALYSIS, AND TRENDS

To facilitate the comparison of EPA fuel economy test results and magazine generated fuel economy figures, a framework was established which links the two sources.

TABLE 7-1

MAGAZINE IN-USE FUEL ECONOMY TEST PROCEDURES

	"City"	"Highway"	Mixed-Mode
Consumer Reports	x	x	x
Consumers' Research		x	
Consumer Guide	x	x	x
Motor Trend			x
Car and Driver	x	x	
Road and Track			x

After looking at several methods of comparison, it was determined that the best method for establishing general relationships between the EPA fuel economy tests and the magazine in-use tests would be calculating average mile-per-gallon differences between EPA estimates and magazine test results. The numerical difference was defined as the EPA fuel economy for a particular car in a certain driving mode minus the magazine fuel economy figure for the identical car in a corresponding driving mode. The result from this calculation is always called the shortfall, (not to be confused with the difference between EPA and actual on-road mpg) no matter what its sign. A negative shortfall indicates that the magazine fuel economy figures is higher than the respective EPA figure.

7.4.1 Data Collection

The data for this analysis were collected by surveying road tests in the subject magazines. Fuel economy test results and automobile characteristics were noted in order to match the magazine data with the correct entries in the EPA/DOE Fuel Economy Guide. The important characteristics are:

- Make
- Model
- Year
- Engine Displacement
- Fuel System
- Transmission.

Using this information, each model having magazine fuel economy estimates was assigned the proper EPA city, highway, and composite fuel economy value. The distribution of the models tested according to size and origin of manufacturer is shown on Table 7-2.

TABLE 7-2

SIZE AND ORIGIN DISTRIBUTION OF CAR MODELS IN DATA BASE

Size Class	Number of Models
Mini-Compact	6
Subcompact	39
Compact	16
Mid-Size	24
Large	13
Small Station Wagon	4
Mid-Size Station Wagon	3
Large Station Wagon	1
TOTAL	106

Origin of Manufacture	Number of Models
Domestic	66
Import	40
TOTAL	106

7.4.2 Data Analysis

Once grouped according to driving mode, the magazine tests had to be matched with the comparable EPA driving mode in order to evaluate divergence from the EPA values. The shortfall conventions can be seen in Table 7-3. Because the Consumer Research 45 MPH test was difficult to assign to a driving-mode and because only three data points derived from this test were collected, the results from the 45 MPH test are not included in the comparisons.

The resulting data are organized into seven tables. These tables will illuminate the trends in each magazine's fuel economy test results and permit magazine-to-magazine and magazine-to-EPA comparison of the following trends:

- Tables 7-4, 7-5, and 7-6 represent the shortfall results for city, highway, and mixed driving modes, respectively, disaggregated by magazine and year.
- Table 7-7 shows the aggregation of the data for the entire period, disaggregated by magazine and driving mode.
- Tables 7-8, 7-9, and 7-10 display the shortfall results from a narrowed* sample in city, highway, and mixed driving modes, respectively, disaggregated by automobile and magazine. Also included are shortfall results drawn from the on-road data base described in Sections 5 and 6.

Tables 7-4, 7-5, 7-6, and 7-7 will be useful to demonstrate the overall trends of fuel economy testing in the subject magazines. Tables 7-8, 7-9, and 7-10 will show how the magazine's testing procedures compare to each other by examining fuel economy test results for the same or similar automobiles. Information on the tables includes:

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* The narrowed sample includes a selection of the most popular cars tested by the magazines. This sample includes 23 model types, compared to the 106 models covered in the analysis of the full sample.

TABLE 7-3

FUEL ECONOMY SHORTFALL CONVENTION: SHORTFALL = EPA ESTIMATE - MAGAZINE TEST RESULT CALCULATION PAIRING BY MAGAZINE

EPA VALUES		MAGAZINE VALUES
	Consumer Reports	
EPA City	-	Magazine In-Use City
EPA Highway	-	Magazine In-Use Highway (55 mph)
EPA Combined	-	Magazine 195-mile Test Cycle
	Consumers' Research	
EPA Highway	-	Magazine In-Use Highway (55 mph)
	Consumer Guide	
EPA City	-	Magazine In-Use City
EPA Highway	-	Magazine In-Use Highway
EPA Combined	-	Magazine In-Use Cumulative Average
	Motor Trend	
EPA Combined	-	Magazine 73-mile Test Cycle
	Car and Driver	
EPA City	-	Magazine Dynamometer City
EPA Highway	-	Magazine Dynamometer Highway
	Road and Track	
EPA Combined	-	Magazine In-Use Cumulative Average

TABLE 7-4

SHORTFALL CITY-DRIVING MODE

(EPA City Minus Magazine In-Use City)

Year	Consumer Reports	Consumer Guide	Car and Driver
1978	Mean Shortfall: 7.6 mpg EPA City Mean: 23.1 mpg Sample Size: 20		Mean Shortfall: -2.2 mpg EPA City Mean: 24.3 mpg Sample Size: 24
1979	Mean Shortfall: 6.0 mpg EPA City Mean: 20.4 mpg Sample Size: 60	Mean Shortfall: 0.0 mpg EPA City Mean: 16.2 mpg Sample Size: 6	Mean Shortfall: -3.5 mpg EPA City Mean: 23.7 mpg Sample Size: 3
1980	Mean Shortfall: 6.5 mpg EPA City Mean: 24.0 mpg Sample Size: 47	Mean Shortfall: -0.4 mpg EPA City Mean: 20.9 mpg Sample Size: 21	

TABLE 7-5

SHORTFALL HIGHWAY-DRIVING MODE

(EPA Highway Minus Magazine In-Use Highway)

Year	Consumer Reports	Consumers' Research	Consumer Guide	Car and Driver
1978	Mean Shortfall: 2.9 mpg EPA Highway Mean: 31.5 mpg Sample Size: 20	Mean Shortfall: 4.1 mpg EPA Highway Mean: 29.7 mpg Sample Size: 7		Mean Shortfall: 5.3 mpg EPA Highway Mean: 34.0 mpg Sample Size: 24
1979	Mean Shortfall: 1.6 mpg EPA Highway Mean: 28.4 mpg Sample Size: 60	Mean Shortfall: 2.4 mpg EPA Highway Mean: 26.8 mpg Sample Size: 6	Mean Shortfall: 0.8 mpg EPA Highway Mean: 22.8 mpg Sample Size: 5	Mean Shortfall: 5.7 mpg EPA Highway Mean: 35.0 Sample Size: 3
1980	Mean Shortfall: 0.5 mpg EPA Highway Mean: 34.8 mpg Sample Size: 47	Mean Shortfall: 4.2 mpg EPA Highway Mean: 36.7 mpg Sample Size: 13	Mean Shortfall: 1.7 mpg EPA Highway Mean: 31.0 mpg Sample Size: 22	

TABLE 7-6

SHORTFALL MIXED-DRIVING MODE

(EPA Combined Minus Magazine In-Use Mixed Mode)

Year	Consumer Reports	Consumer Guide	Motor Trend	Road and Track
1978	Mean Shortfall: 1.2 mpg EPA Combined Mean: 26.1 mpg Sample Size: 19		Mean Shortfall: 0.7 mpg EPA Combined Mean: 23.9 mpg Sample Size: 10	Mean Shortfall: 2.5 mpg EPA Combined Mean: 25.3 mpg Sample Size: 14
1979	Mean Shortfall: -0.7 mpg EPA Combined Mean: 23.6 mpg Sample Size: 26	Mean Shortfall: -0.5 mpg EPA Combined Mean: 23.7 mpg Sample Size: 34	Mean Shortfall: -0.7 mpg EPA Combined Mean: 24.4 mpg Sample Size: 2	Mean Shortfall: 0.9 mpg EPA Combined Mean: 26.3 mpg Sample Size: 16
1980	Mean Shortfall: -3.4 mpg EPA Combined Mean: 30.4 mpg Sample Size: 29	Mean Shortfall: 0.0 mpg EPA Combined Mean: 24.5 mpg Sample Size: 25	Mean Shortfall: -3.1 mpg EPA Combined Mean: 27.7 mpg Sample Size: 31	Mean Shortfall: 4.9 mpg EPA Combined Mean: 29.3 mpg Sample Size: 31

TABLE 7-7

AVERAGE SHORTFALL ALL DRIVING MODES FOR 1978-1980 CARS

(EPA Minus Magazine In-Use)

Driving Mode	Consumer Reports	Consumers' Research	Consumer Guide	Motor Trend	Car and Driver	Road and Track
City Mode Fuel Economy 1978-1980	Mean Shortfall: 6.4 mpg EPA City Mean: 22.3 mpg Sample Size: 127		Mean Shortfall: -0.3 mpg EPA City Mean: 19.9 mpg Sample Size: 27 [1979, 1980]		Mean Shortfall: -2.3 mpg EPA City Mean: 24.3 mpg Sample Size: 27 [1978, 1979]	
Highway-Mode Fuel Economy 1978-1980	Mean Shortfall: 1.4 mpg EPA Highway Mean: 31.2 mpg Sample Size: 127	Mean Shortfall: 3.8 mpg EPA Highway Mean: 32.5 mpg Sample Size: 26	Mean Shortfall: 1.5 mpg EPA Highway Mean: 29.5 mpg Sample Size: 27 [1979, 1980]		Mean Shortfall: 5.3 mpg EPA Highway Mean: 34.1 mpg Sample Size: 27 [1978, 1979]	
Mixed-Mode Fuel Economy 1978-1980	Mean Shortfall: -1.2 mpg EPA Combined Mean: 26.9 mpg Sample Size: 74		Mean Shortfall: -0.3 mpg EPA Combined Mean: 24.0 mpg Sample Size: 59 [1979, 1980]	Mean Shortfall: -1.7 mpg EPA Combined Mean: 26.0 mpg Sample Size: 63		Mean Shortfall: 3.3 mpg EPA Combined Mean: 27.6 mpg Sample Size: 61

- Mean shortfall expressed in mpg
- Mean EPA fuel economy figure
- Number of data points from which mean shortfall is calculated.

7.4.3 Trends in the Full Sample

Table 7-4 shows that the three magazines carrying out city fuel economy tests have a large variance in fuel economy estimates and related shortfall. Consumer Reports is much below the EPA figures, Consumer Guide is close to the EPA figures, and Car and Driver is above the EPA data.

The highway driving-mode results, shown in Table 7-5, show that although the mean shortfalls for all the publications were positive (magazine fuel economy estimates lower than the EPA figures), significant variation is evident among the four magazines. Consumer Reports and Consumer Guide show results rather close to EPA figures, while the Car and Driver and Consumers' Research numbers were much lower than EPA results.

Examination of Table 7-6 shows some divergent shortfall trends over time. While Consumer Reports and Motor Trend shortfalls were decreasing in the period 1978-1980, Road and Track shows a sharp increase in shortfall in 1980 and Consumer Guide a slight increase. Considerable agreement between magazines is evident when comparing Consumer Reports and Motor Trend results.

7.4.4 Trends in the "Narrow Sample" (23 Model Types)

Pertaining to city-mode fuel economy in the narrow sample (see Table 7-8), Consumer Reports produced results consistently below EPA fuel economy figures. Consumer Guide figures generally proved to be a little higher than EPA numbers, with Car and Driver fuel economies mostly quite a bit higher than EPA results. Variation among the different magazines'

TABLE 7-8
SHORTFALL CITY-DRIVING MODE
(EPA City minus Magazine City Mode)

Automobile	Consumer Reports	Consumer Guide	Car and Driver	On Road Data Base*
Dodge Colt Plymouth Champ				
Mean Shortfall	8.8 mpg			
EPA City Mean	33.0 mpg			
Sample Size	1			
Honda Civic				
Mean Shortfall	10.6 mpg		-1.0 mpg	5.6 mpg
EPA City Mean	36.0 mpg		36.0 mpg	32.8 mpg
Sample Size	2		1	5
Volkswagen Rabbit Gasoline				
Mean Shortfall	5.4 mpg		-6.8 mpg	-2.3 mpg
EPA City Mean	25.7 mpg		25.0 mpg	24.8 mpg
Sample Size	3		2	17
Volkswagen Rabbit Diesel				
Mean Shortfall	12.5 mpg			
EPA City Mean	41 mpg			
Sample Size	2			
Oldsmobile Cutlass Gasoline				
Mean Shortfall	7.7 mpg			2.1 mpg
EPA City Mean	19.5 mpg			18.8 mpg
Sample Size	2			84
Oldsmobile Cutlass Diesel				
Mean Shortfall	9.7 mpg	-1.0 mpg		-3.0 mpg
EPA City Mean	24.0 mpg	22.0 mpg		24.0 mpg
Sample Size	1	1		1
Buick Riviera				
Mean Shortfall		-1.0 mpg		2.5 mpg
EPA City Mean		16.0 mpg		16.0 mpg
Sample Size		1		2
Ford Fairmont Mercury Zephyr				
Mean Shortfall	6.4 mpg		-1.5 mpg	1.6 mpg
EPA City Mean	19.7 mpg		16.0 mpg	18.7 mpg
Sample Size	7		1	25
Ford Fiesta				
Mean Shortfall	10.3 mpg		-1.5 mpg	3.4 mpg
EPA City Mean	34.0 mpg		34.0 mpg	32.5 mpg
Sample Size	1		1	8
Dodge Omni Plymouth Horizon				
Mean Shortfall	4.7 mpg		-4.0 mpg	-1.3 mpg
EPA City Mean	24.8 mpg		25.0 mpg	24.2 mpg
Sample Size	4		2	42

TABLE 7-8 (Cont'd)

SHORTFALL CITY-DRIVING MODE

(EPA City minus Magazine City Mode)

Automobile	Consumer Reports	Consumer Guide	Car and Driver	On Road Data Base*
AMC Concord				
Mean Shortfall	5.6 mpg	0.0 mpg		-0.3 mpg
EPA City Mean	18.7 mpg	17.5 mpg		17.7 mpg
Sample Size	3	2		10
Fiat Strada				
Mean Shortfall	5.5 mpg			
EPA City Mean	28.0 mpg			
Sample Size	7			
Chevrolet Citation, Buick Skylark, Oldsmobile Omega, Pontiac Phoenix				
Mean Shortfall	6.0 mpg	-1.7 mpg		
EPA City Mean	21.7 mp	20.3 mpg		
Sample Size	2	3		
Ford Mustang, Mercury Capri				
Mean Shortfall	4.3 mpg			2.7 mpg
EPA City Mean	19.5 mpg			21.6 mpg
Sample Size	2			220
Toyota Tercel				
Mean Shortfall	7.7 mpg	-3.0 mpg		
EPA City Mean	31.0 mpg	31.0 mpg		
Sample Size	1	1		
Renault LeCar				
Mean Shortfall	6.9 mpg		-6.0 mpg	
EPA City Mean	30.1 mpg		26.0 mpg	
Sample Size	1		1	

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*Mean shortfall observed in on road data base used in Sections 5 and 6.

results are very obvious. Further, there is little correlation between the city-mode results of any magazine and the on-road shortfalls derived from the data bases used in Sections 5 and 6. The Consumer Reports city-mode shortfalls were quite a bit larger than actual on-road shortfalls. The Consumer Guide results generally tended to be in the correct direction, though not necessarily close to the on-road results. The Car and Driver tests showed higher fuel economies (lower shortfalls) than the actual on-road data displayed.

Highway-mode fuel economy test comparisons displayed fewer consistent EPA-magazine relationships than evidenced in the city-mode (see Table 7-9). The results from Consumer Reports and Consumer Guide appeared to be randomly scattered around the EPA estimates. Consumers' Research figures tended to be lower than EPA numbers. Car and Driver figures were consistently much lower than EPA test results. When compared with this paper's on-road shortfall results, the results from both Car and Driver and Consumers' Research are directionally correct. Very little can be drawn from the Consumer Guide entries. The Consumer Reports highway results generally projected lower shortfalls than those drawn from the on-road data bases.

Examination of the mixed mode fuel economy figures in Table 7-10 demonstrates additional variability between magazines. Fuel economy figures published by Consumer Reports were higher than EPA numbers, for the most part, as were the figures in Motor Trend. Consumer Guide results showed no consistent relationship to the EPA numbers. Finally, Road and Track proved reliably consistent in showing fuel economy numbers well below EPA fuel economy numbers. In a Consumer Reports/on-road data base comparison, the magazine-generated shortfalls seem to be a little lower (higher fuel economy) than actual on-road results, though the differences are not usually great. This statement basically applies to Consumer Guide also -- a tendency to produce slightly higher fuel economy test results than can be demonstrated in actual on-road mixed-mode driving. Motor Trend

TABLE 7-9
SHORTFALL HIGHWAY-DRIVING MODE

(EPA Highway Minus Magazine Highway-Mode)

Automobile	Consumer Reports	Consumers' Research	Consumer Guide	Car and Driver	On Road Data Base*
Dodge Colt **Plymouth Camp**					
Mean Shortfall	1.8 mpg	4.5 mpg			4.0 mpg
EPA Highway Mean	43.0 mpg	44.0 mpg			40.0 mpg
Sample Size	1	1			1
Honda Civic					
Mean Shortfall	2.3 mpg	7.5 mpg		5.0 mpg	5.0 mpg
EPA Highway Mean	46.5 mpg	49.0 mpg		44.0 mpg	37.3 mpg
Sample Size	2	1		1	3
Volkswagen Rabbit **Gasoline**					
Mean Shortfall	2.4 mpg			2.8 mpg	7.9 mpg
EPA Highway Mean	39.7 mpg			38.0 mpg	36.7 mpg
Sample Size	3			2	35
Volkswagen Rabbit **Diesel**					
Mean Shortfall	5.6 mpg				
EPA Highway Mean	54.5 mpg				
Sample Size	2				
Oldsmobile Cutlass **Gasoline**					
Mean Shortfall	3.1 mpg				7.5 mpg
EPA Highway Mean	27.0 mpg				25.6 mpg
Sample Size	2				94
Oldsmobile Cutlass **Diesel**					
Mean Shortfall	2.9 mpg		3.0 mpg		10.3 mpg
EPA Highway Mean	32.0 mpg		34.0 mpg		32.0 mpg
Sample Size	1		1		4
Buick Riviera					
Mean Shortfall		-2.5 mpg			4.0 mpg
EPA Highway Mean		23.0 mpg			22.0 mpg
Sample Size		1			3
Ford Fairmont **Mercury Zephyr**					
Mean Shortfall	2.3 mpg			5.0 mpg	6.0 mpg
EPA Highway Mean	28.0 mpg			23.0 mpg	26.2 mpg
Sample Size	7			1	39
Ford Fiesta					
Mean Shortfall	7.2 mpg	7.5 mpg		10.0 mpg	11.8 mpg
EPA Highway Mean	46.0 mpg	46.0 mpg		46.0 mpg	44.7 mpg
Sample Size	1	1		1	16
Dodge Omni **Plymouth Horizon**					
Mean Shortfall	1.3 mpg	7.0 mpg		8.5 mpg	6.9 mpg
EPA Highway Mean	36.5 mpg	38.0 mpg		38.0 mpg	35.1 mpg
Sample Size	4	1		2	67

TABLE 7-9 (Continued)

SHORTFALL HIGHWAY-DRIVING MODE

(EPA Highway Minus Magazine Highway-Mode)

Automobile	Consumer Reports	Consumers' Research	Consumer Guide	Car and Driver	On Road Data Base*
AMC Concord					
Mean Shortfall	-1.4 mpg	0.0 mpg	2.3 mpg		5.5 mpg
EPA Highway Mean	24.0 mpg	21.0 mpg	24.0 mpg		24.3 mpg
Sample Size	3	1	2		13
Fiat Strada					
Mean Shortfall	3.7 mpg	-1.0 mpg			
EPA Highway Mean	41.0 mpg	35.0 mpg			
Sample Size	1	1			
Chevrolet Citation, Buick Skylark, Oldsmobile Omega, Pontiac Phoenix					
Mean Shortfall	0.8 mpg	4.0 mpg	-1.3 mpg		
EPA Highway Mean	34.0 mpg	34.0 mpg	33.7 mpg		
Sample Size	7	1	3		
Ford Mustang, Mercury Capri					
Mean Shortfall	-0.3 mpg				11.8 mpg
EPA Highway Mean	43.0 mpg				34.2 mpg
Sample Size	2				201
Toyota Tercel					
Mean Shortfall	3.5 mpg	7.0 mpg	-3.0 mpg		
EPA Highway Mean	43.0 mpg	43.0 mpg	43.0 mpg		
Sample Size	1	1	1		
Renault LeCar					
Mean Shortfall	-1.4 mpg	6.0 mpg		5.0 mpg	
EPA Highway Mean	40.0 mpg	40.0 mpg		41.0 mpg	
Sample Size	1	1		1	

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*Mean shortfall observed in on road data base used in Sections 5 and 6.

TABLE 7-10
SHORTFALL MIXED-DRIVING MODE
(EPA Combined Minus Magazine Mixed Mode)

Automobile	Consumer Reports	Consumer Guide	Motor Trend	Road and Track	On Road Data Base*
Dodge Colt Plymouth Champ					
Mean Shortfall	1.3 mpg	1.5 mpg	-10.0 mpg	7.7 mpg	2.5 mpg
EPA Combined Mean	37.0 mpg	36.5 mpg	36.0 mpg	36.3 mpg	35.5 mpg
Sample Size	1	2	1	3	2
Honda Civic					
Mean Shortfall	0.2 mpg	0.0 mpg	-0.8 mpg	13.3 mpg	2.5 mpg
EPA Combined Mean	40.5 mpg	38.0 mpg	40.3 mpg	41.0 mpg	33.4 mpg
Sample Size	2	1	4	2	26
Volkswagen Rabbit Gasoline					
Mean Shortfall	-4.1 mpg	-4.0 mpg	-2.0 mpg	5.0 mpg	-0.9 mpg
EPA Combined Mean	30.3 mpg	31.0 mpg	30.0 mpg	31.0 mpg	28.7 mpg
Sample Size	3	1	1	2	143
Volkswagen Rabbit Diesel					
Mean Shortfall	2.3 mpg	0.8 mpg			0.1 mpg
EPA Combined Mean	46.0 mpg	47.0 mpg			44.3 mpg
Sample Size	2	1			71
Oldsmobile Cutlass Gasoline					
Mean Shortfall	2.1 mpg	0.0 mpg	2.5 mpg		3.7 mpg
EPA Combined Mean	22.0 mpg	22.0 mpg	22.0 mpg		21.6 mpg
Sample Size	1	1	1		780
Oldsmobile Cutlass Diesel					
Mean Shortfall	3.1 mpg	6.0 mpg			2.5 mpg
EPA Combined Mean	27.0 mpg	27.0 mpg			25.4 mpg
Sample Size	1	1			45
Buick Riviera					
Mean Shortfall		-3.0 mpg	-4.8 mpg	3.0 mpg	2.2 mpg
EPA Combined Mean		18.0 mpg	18.0 mpg	18.0 mpg	17.8 mpg
Sample Size		1	1	1	10
Ford Fairmont Mercury Zephyr					
Mean Shortfall	0.7 mpg	1.5 mpg	1.0 mpg	5.0 mpg	3.2 mpg
EPA Combined Mean	22.7 mpg	23 mpg	23.5 mpg	23.0 mpg	21.9 mpg
Sample Size	6	1	2	1	1709
Ford Fiesta					
Mean Shortfall	1.9 mpg	-6.3 mpg	-3.7 mpg	2.5 mpg	0.9 mpg
EPA Combined Mean	38.0 mpg	31.0 mpg	31.0 mpg	30 mpg	31.3 mpg
Sample Size	1	2	2	1	648
Dodge Omni Plymouth Horizon					
Mean Shortfall	-4.4 mpg	1.0 mpg	-0.7 mpg	2.5 mpg	0.5 mpg
EPA Combined Mean	30.0 mpg	28.5 mpg	28.5 mpg	28.0 mpg	28.1 mpg
Sample Size	2	2	2	2	235

TABLE 7-10 (Continued)

SHORTFALL MIXED-DRIVING MODE

(EPA Combined Minus Magazine Mixed Mode)

Automobile	Consumer Reports	Consumer Guide	Motor Trend	Road and Track	On Road Data Base
AMC Concord					
Mean Shortfall	-0.6 mpg				1.8 mpg
EPA Combined Mean	20.7 mpg				21.6 mpg
Sample Size	3				192
Fiat Strada					
Mean Shortfall	-5.3 mpg	-1.0 mpg	-1.7 mpg	3.0 mpg	
EPA Combined Mean	32.0 mpg	29.0 mpg	30.5 mpg	30.5 mpg	
Sample Size	1	1	2	2	
Chevrolet Citation, Buick Skylark, Oldsmobile Omega, Pontiac Phoenix					
Mean Shortfall	-3.3 mpg		2.3 mpg	1.5 mpg	2.6 mpg
EPA Combined Mean	25.8 mpg		25.0 mpg	24.3 mpg	26.1 mpg
Sample Size	5		2	4	15
Ford Mustang Mercury Capri					
Mean Shortfall	-2.2 mpg	0.3 mpg	-1.3 mpg	2.5 mpg	5.2 mpg
EPA Combined Mean	22.0 mpg	21.7 mpg	20.5 mpg	22.0 mpg	25.8 mpg
Sample Size	2	3	2	1	1093
Toyota Tercel					
Mean Shortfall	-3.1 mpg		-11.0 mpg	7.0 mpg	
EPA Combined Mean	35.0 mpg		35.0 mpg	35.0 mpg	
Sample Size	1		1	1	
Renault LeCar					
Mean Shortfall	-7.9 mpg	-2.0 mpg	-8.0 mpg	9.0 mpg	
EPA Combined Mean	33.0 mpg	32.0 mpg	33.0 mpg	33.0 mpg	
Sample Size	1	2	1	1	

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*Mean shortfall observed in on road data base used in Sections 5 and 6.

mixed-mode shortfalls also appeared to be on the low side of the on-road results, but to a much greater extent than either Consumer Reports or Consumer Guide. Road and Track results diverged significantly from any trends evident in the other magazines; shortfalls tended to be higher (indicating lower fuel economy) than on-road data base shortfalls.

7.5 Conclusions

The previous analysis shows that the fuel economy data from test procedures developed by magazines with interests in automobiles do not demonstrate any uniform relationship to the results of EPA fuel economy tests. Furthermore, as illustrated by the "narrow sample" results, there is no assurance that different magazines will arrive at similar fuel economy estimates for any particular vehicle. This makes the prediction of a vehicle's actual fuel economy from the magazine test data impossible. Therefore, the magazine fuel economy test results prove no more helpful to the general public at predicting actual vehicle fuel economy than EPA fuel economy figures.

The comparison between magazine fuel economy results and the on-road data base figures drawn from Sections 5 and 6 does not enable one to conclude that any particular magazine fuel economy test accurately predicts vehicle on-road fuel economy.

The Consumer Reports city-mode test over a one mile simulated urban driving course seems to have a strong negative effect on fuel economy. Convesely, the Consumer Reports highway and mixed mode tests produce fuel economy results that are a little higher than vehicles usually achieve in actual on-road situations. Consumers' Research developed figures for highway driving that, though not exact, generally indicate the proper trend away from EPA fuel economy estimates. Fuel economy figures from Consumer Guide produce a mixed result when compared to actual on-raod driving, and tend to follow EPA estimates. The mixed-mode results published in Motor Trend, drawn from a 73 mile driving cycle, are generally higher than fuel economies displayed in the on-road data base. The Car and Driver dynamometer testing seems reasonably successful in predicting correct directions for shortfall trends, though the magnitude of the magazine shortfalls is always exaggerated in comparison to the on-road fuel economy results. Road and Track also demonstrated a higher degree of directional correctness in its mixed-mode results, although the size of its shortfalls was almost always significantly larger than the on-road data base indicates the driving public actually experiences. In addition, no magazine fuel economy test reflects the technology-based fuel economy changes demonstrated by on road data base analysis. Fuel economy tests carried out by the magazines do not demonstrate the fuel economy advantage in front wheel drive or diesel vehicles, advantages that are evident in the analysis of the on-road data base.

In some cases, reliance on magazine-generated fuel economy figures may mislead the general public about actual fuel economy to an even greater extent than EPA figures do at the present time. The fuel economy figures for mixed-mode driving published by Consumer Reports, Consumer Guide, and Motor Trend, are usually higher than the combined fuel economy figures calculated by the Environmental Protection Agency. Yet, it is known, the actual average fuel economy values for conventional vehicles can be more than 10 percent lower than the EPA combined figures.

In several cases, it is possible to tie specific magazine test procedures to fuel economy results. The precise, mixed-mode driving cycles carried out by Consumer Reports and Motor Trend tended to boost the resulting fuel economy figures above combined EPA numbers, and actually produced close correlation between the two magazines. Road and Track's admittedly "spirited" road testing of relatively lengthy duration tended to produce fuel economy figures lower than EPA results.

On the other hand, correlation did not always appear where it might have been expected. For example, the use of similar, constant speed highway fuel economy tests by Consumer Reports and Consumers' Research produced significantly different results.

Additionally, expected within-class agreement (among consumer magazine trends, and among automotive enthusiast-magazine trends) was never overwhelmingly apparent. The consumer magazines showed divergence in the city mode and highway mode tests. Slight conformity between Consumer Reports and Consumers Guide in the mixed-mode and highway mode results did provide some notes of agreement. Such was not the case for the automotive enthusiast magazines. In the only area of common testing, Motor Trend and Road and Track showed great variation in the results of their mixed-mode fuel economy tests.

In short, the fuel economy information dilemma voiced by the Federal Trade Commission vis a vis magazine fuel economy has not changed[4/]. Magazine fuel economy test procedures of recent years provide no reliable estimate of on-road fuel economy.

FOOTNOTES FOR SECTION 7

1/ "How CU Tests and Rates Cars." *nsumer Reports*, April 1980, p. 236.

2/ *Ibid*., p. 236.

3/ Interview with Don Sherman, Technical Editor, *Car and Driver*. February 26, 1981.

4/ Federal Trade Commission, Rulemaking Notice Pertaining to Auto Fuel Economy Promotion and Advertising, Federal Register *39*, at 34382, quoted in U.S. Environmental Protection Agency, 1980, *Passenger Car Fuel Economy: EPA and Road*, EPA 460/3-80-010, Ann Arbor, Mi.: EPA, January 1980, p. 15.

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8. SUMMARY AND CONCLUSIONS

The purpose of this analysis has been to evaluate and quantify the differences between EPA test-measured and actual on-road fuel economy. It is expected that the methodology and the adjustment factors developed in this analysis will form the basis for a labeling system that, in future model years, will discount the EPA test measurements of new cars to estimate on-road fuel economy. Because new cars employ a growing percentage of fuel-efficient technologies having distinctly lower levels of shortfall than traditional ones, this analysis has carefully evaluated and, to the extent that available data permit, quantified the shortfall of the alternative technologies.

This summary can provide one of two statements: a list of the conclusions reached within the study or a discussion of the implications of applying the current adjustment factors to the market. It is assumed that the technical conclusions stated in the course of the text are clear and do not need reinforcement. The implications of applying these factors to a rapidly changing technological market are not as clear, particularly when the differential impacts on manufacturers/ technology are considered.

While current labeling procedures employ single fuel economy values for comparing vehicles, the two-mode system in effect through 1978 provided consumers with more specific information comparable to the bimodal nature of personal travel patterns. The city and highway ratings have been found more useful for comparison shopping since they assist the consumer in choosing a vehicle suited to the intended use. The two-mode labeling system is, therefore, preferable from the consumer perspective.

The recommended adjustment factors developed in Section 6 are very effective on an industry-wide basis in providing the consumer with accurate estimates of on-road fuel economy. This system requires substantial discounting of the highway-cycle dynamometer rating and so compresses the city/highway label range. Yet, the large majority of vehicles are labeled with a meaningful differential which approximates what a typical motorist can expect to achieve in city or highway driving.

The two-mode system can provide fuel economy information that accurately reflects the in-use experience of consumers at large. However, the analysis indicates clearly that the recommended system, based on model year 1978-1979 data might not be equitable for certain models. In an industry-wide analysis using a sales-weighted data base, the typical consumer will own a GM vehicle. That individual will find that the adjusted label values accurately portray his on-road experience. Other consumers may have reason for dissatisfaction.

In particular, the high-mpg RWD-carbureted vehicles appear to have lower shortfall than the larger cars in the 15 to 25 mpg range. These vehicles, produced primarily by Japanese manufacturers during the models years for which data are available, could be mislabeled by as much as five mpg. Evidence also exists that the domestic manufacturers have different shortfall levels. Owners of AMC and Ford RWD-carbureted vehicles may find their cars performing one to two mpg better on the road than indicated by the label values. Under these conditions, manufacturer-specific labeling procedures will probably be requested.

The two-mode factors also may be inequitable for some high-mpg cars now being produced by the domestic industry. During the 1978 and 1979 model years, on which the two-mode analysis is based, few domestic cars were above 30 mpg. A key question for the future is whether the domestic RWD-carbureted technologies will emulate the shortfall of the Japanese or continue the trend of increasing shortfall with increasing mpg. If the on-road performance does not converge, it is quite likely that applying industry-wide adjustment factors will further penalize the foreign manufacturers relative to domestics.

The concern for equity in the labeling of RWD-carbureted cars will diminish as front-wheel drive, diesel engines, and fuel injection become prevalent automotive technologies. This analysis has examined four models offering one or more alternative technologies and finds that front-wheel drive has a large influence on city/highway shortfall. The gasoline powered front-wheel drive subcompacts are penalized approximately 10 percent on the urban-cycle test. Available data demonstrate conclusively that the city GPM factor is less than 1.00. Until further data become available, a FWD adjustment factor common to all such cars appears a credible course of action. Two-mode factors cannot be determined for diesel-powered vehicles, however, or for rear-wheel drive cars (except the TBFI Lincoln) employing fuel-injection.

The adjustment factors developed in this analysis have been derived from the largest available data base describing in-use fuel economy. Nevertheless, a consistent theme in the analysis has been to point out the limitations of these data. The recommended dual mode adjustment factors are applicable only to conventional technologies and gasoline-powered front-wheel drive vehicles. The specification of adjustment factors for the remaining technologies is a problem. The data currently are not available to support the technical development of an industry average factor for these technologies. Therefore, implementing the two-mode system will necessarily require an administrative judgment on which factors will be applied to these vehicles in light of the available data and their importance in the marketplace. The methodology used to develop the two-mode correction factors can be used to develop factors for these technologies when more data become available.